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ILLINOIS RIVER SYSTEM - WATER QUALITY CONDITIONS PART I. TEXT

Public Health Service
Chicago, Illinois

January 1963

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REPORT
ON THE
ILLINOIS RIVER SYSTEM

WATER QUALITY CONDITIONS

Part I Text

January 1963

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Great Lakes-Illinois River Basins Project

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REPORT
ON THE
ILLINOIS RIVER SYSTEM
EFFECTS ON WATER QUALITY OF RECOMMENDED IMPROVEMENT MEASURES

JANUARY, 1963

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE
DIVISION OF WATER SUPPLY AND POLLUTION CONTROL
GREAT LAKES-ILLINOIS RIVER BASINS PROJECT

ERRATA

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Effects on Water Quality of Recommended Improvement Measures

Page 3, first paragraph, second line.
Delete 1,450,000 PE: insert 1,590,000 PE.

Page 3, first paragraph, 13th line. Insert asterisk after 928,600. At bottom of page insert: *In addition to this stated load, a malfunctioning storm relief discharged an estimated 144,000 PE during the period of study.

Page 9, second paragraph, eighth and eleventh lines.
Revise lines as follows:

Chicago-MSD	147,300	36,000	41,790	10,000
Total	725,300	177,000	208,240	50,500

Page 12, item 4. Delete 58,000; insert 26,000

Page 13. Renumber items 7, 8 and 9 to 8, 9 and 10 respectively.
Insert new item 7 as follows:
7. Correction of a malfunctioning storm relief that was observed to be flowing during the study period would decrease the pollution load by an estimated 32,000 pounds of ultimate BOD per day. This correction has been made.

Table 4a, last line. Delete entire line I-5.

Table 4b, last line. Revise numbers to read as follows: 169.65; 243,100; 76,200; 7,260.

Table 6, Insert asterisks after title and preceding last line on page.

Table 6, Upper Illinois River System
Present Total BOD Load.
b. Industrial. Delete 71,000; insert 36,000.

Insert new line d as follows:
d. Malfunctioning Storm Relief 35,000

BOD Reduction by Improvements.
b. Industrial Waste Reduction. Delete 58,000; insert 26,000
Insert new line f, as follows:
f. Correct Storm Relief 32,000

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Water Quality Conditions; Part I, Text.

Page II-3, fifth paragraph. Delete last three words.

Page II-4. Delete last paragraph.

Page II-5. Under Industrial Water Supplies insert new first paragraph:

> The industrial use of water other than for power generation is about 1500 MGD. Total municipal and industrial water use in the basin, excluding power generation, is about 3900 MGD.

Page II-5, 20th line. Add sentence: This does not include water used for cooling in thermal power plants but does include cooling water used by industry.

Page II-9. Delete seventh and eighth lines. Insert: Investigations by GLIRBP indicate that silt destroyed the rooted aquatic plants, the normal habitat of the molluscs. This was accomplished by silt covering the young emerging plants during spring floods; and by causing turbid conditions which would not let light penetrate the water to supply energy to the plants.

Page III-1, second paragraph. Revise as follows: Municipal Wastes 1,590,000 PE, Industrial Wastes 827,000 PE.

Page III-2, 34th line. Add sentence: In addition to this stated load, a malfunctioning storm relief discharged an estimated 144,000 PE during the period of study.

Page III-4, 20th line. Delete 971,000 PE; insert 827,000 PE.

Page III-4, 24th line. Delete 13; insert 12.

Page III-4, 27th line. Delete 42; insert 41. Delete 387,100; insert 243,100.

Page III-4, 28th line. Delete 35; insert 36.

Page III-4, 32nd line. Delete 21; insert 25.

Page III-4, 40th line. Delete 183; insert 186. Delete 971,000; insert 827,100.

Page III-5, 17th line. Delete 224,900 PE; insert 80,900 PE. Delete 12 per cent; insert 4.3 per cent.

Page III-6, last paragraph. Revise second and third sentences as follows: Approximately 40 per cent of this load has been accounted for in the municipal and industrial waste inventory. The remaining 60 per cent of this load is in addition to the municipal and industrial waste inventory.

Page V-14, second paragraph, second line. Insert "CS" ahead of "320.2."

Page V-16, 16th line. Delete "system";insert "Main Stem."

Page VII-13, third line from bottom. Delete VII-3a; insert VII-2a.

Page VII-15, sixth line from bottom. Delete "most"; insert "all."

Page VIII-3, 23rd line. Delete 969,000; insert 938,000.

Page VIII-4, 20th line. Delete 969,000; insert 938,000.

Page VIII-4, 21st line. Delete 1,608,000; insert 1,639,000.

Page VIII-10, 24th line. Delete last four lines of paragraph; insert "presented in Table IX-2, average about 157,000 pounds of ultimate BOD per day for the same period. This figure includes storm spillage estimated at 56,000 pounds ultimate BOD daily and industrial waste loads of 20,000 pounds ultimate BOD daily."

Page VIII-13, fourth paragraph. Last number is VIII-8.

Page X-1, fourth paragraph, third line. Delete 1,400,000; insert 1,600,000. Delete 1,000,000; insert 800,000.

Page X-1, fourth paragraph, sixth line. Delete 1,000,000; insert 1,150,000.

Page X-3, third line. Delete "prescribed Radiation Protection Guides"; insert "the limits recommended by the PHS Drinking Water Standards of 1962."

Page X-3, paragraph No. 9. Delete entire paragraph and insert new paragraph No. 9 as follows:

9. A quantitative evaluation of the organic waste loads discharged to the Upper Illinois River system indicates the presence of substantial sources of oxygen demand. These include known loads from treatment plants and tributaries totalling approximately 200,000 pounds per day ultimate BOD. There are loads from other sources such as industrial wastes, storm spillage, malfunctioning storm reliefs, and resuspended sludge deposits totalling approximately 160,000 pounds per day. Included in the 160,000 pounds per day is about 60,000 pounds per day of oxygen demand from bottom sludge. The total load of 360,000 pounds per day was determined from results of numerous laboratory analyses. This load exceeds the natural assimilation capacity of the stream. This is summarized in Table IX-14 which shows average oxygen assets of only 27,000 pounds per day and BOD liabilities of 134,000 pounds per day at Lockport. It is further illustrated in Figures V-5 through V-7 which show observed depletion of dissolved oxygen in the stream.

Water Quality Conditions; Part II, Tables

After Table II-17. Insert information as follows:

Municipal Water Treatment Code

P	Purification
H	Softening
I	Iron or manganese removal
D	Disinfection
V	Fluoride adjustment
Va	Hydrofluosilicic acid
Vs	Sodium silicofluoride
Vt	Sodium fluoride
( )	Indicates treatment performed by another plant.

Table II-18. Delete footnote (c).

Table III-1 Insert asterisks after 713,200 and 1,446,030 in extreme right column.

Insert at bottom: *Plus 144,000 PE from malfunctioning storm relief.

Table III-3a. Insert asterisks after 651,700 and 713,200 in extreme right column.

Table III-3b. Insert at bottom: *Plus 144,000 PE from malfunctioning storm relief.

Table III-13, column (3). Revise miles as follows:

Fisher	202-1
Mahomet	189
Assumption	87-57-18-7
Taylorville S.E. Plant	87-59
Morrisonville	87-45-9-7
Taylorville N.W. Plant	87-48-4
Kinkaid	87-40
Gibson City	214-8
Macon	87-57-17-8
Decatur	129
Virden	87-8-6-18
Petersburg	44
Monticello	165
Cerro Gordo	147-5
Auburn	87-27
Riverton	82
Springfield	73-4
Moweaqua	87-57-20

Table III-19a Delete entire line I-314.8.

Table III-19b, subtotal. Delete 190.65; insert 169.65. Delete 387,100; insert 243,100.

Table III-19f, Grand total. Delete 676.45; insert 655.45. Delete 971,100; insert 827,100.

Table III-21b. Revise last two lines of number as follows:

Included in municipal and industrial inventory	62	284,700	82,600	50,800	139,300
Additional loading including malfunctioning storm reliefs	43	26,000	79,200	76,200	229,200

Table VIII-2, Effluent PE. Delete 751, insert 720. Delete 969; insert 938.

Table IX-1, fourth line from bottom. After "Estimated Industrial Waste" insert "and malfunctioning storm relief."

Table IX-15, line II. After "Industrial wastes" insert "and malfunctioning storm relief load."

Table IX-16. In first column insert 0.090. In second column insert 0.082. In third column insert 0.126 and 0.240.

Water Quality Conditions; Part III, Graphs and Illustrations.

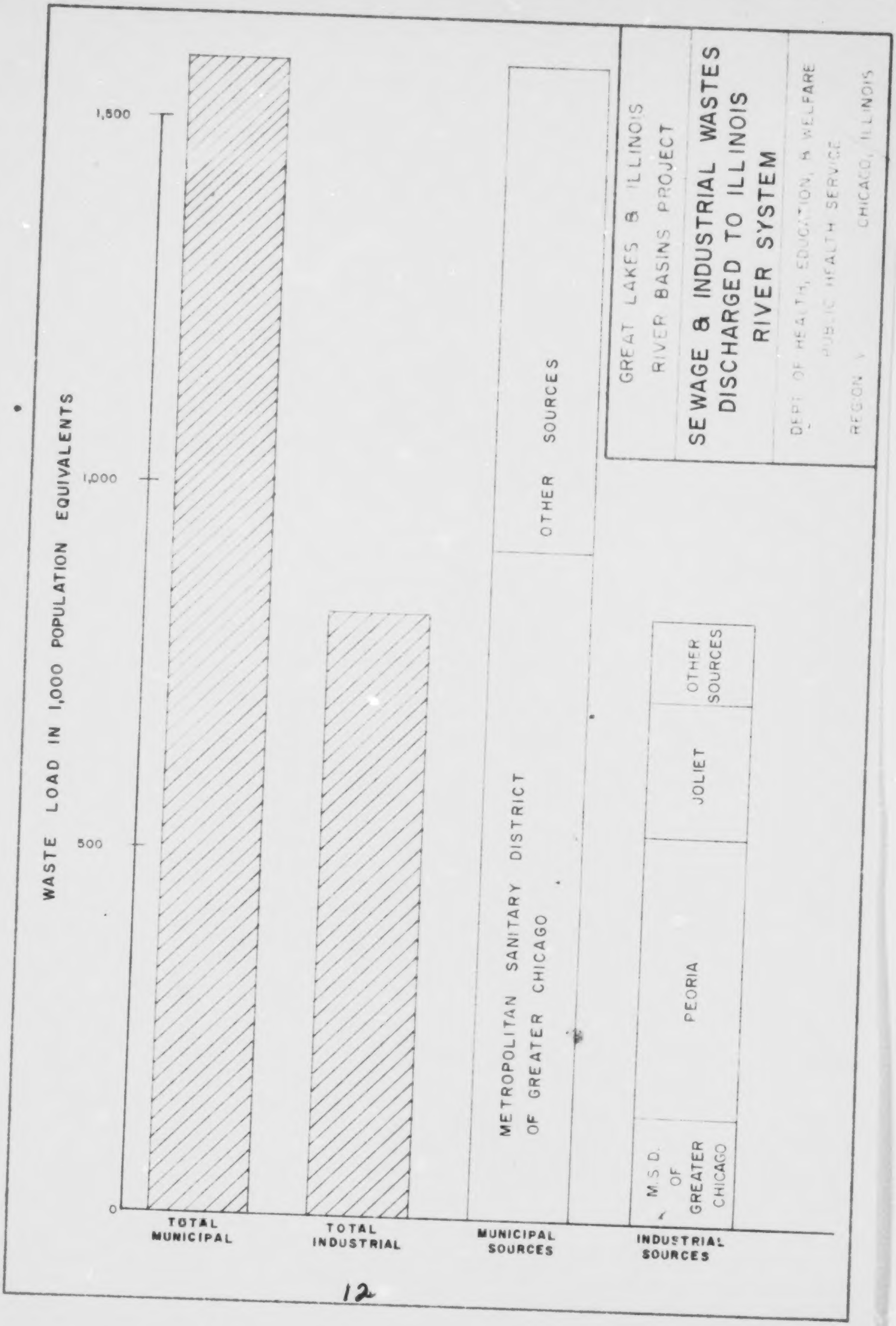
Figure III-1. Substitute revised Figure III-1 attached.

Figure III-5. Delete waste source I-5.

Figure VII-1, Legend, last line. Delete "Summer"; insert "Winter."

Figure VII-3, ordinate scale. Multiply ordinates by ten; insert "Number per 100 ml."

Figure VII-4, ordinate scale. Insert "Number per 100 ml."



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

SEWAGE & INDUSTRIAL WASTES DISCHARGED TO ILLINOIS RIVER SYSTEM

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

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FIGURE III-1

I INTRODUCTION

This is a special report prepared by the Public Health Service, United States Department of Health, Education, and Welfare, at the request of the Department of Justice. The report presents the results of comprehensive investigations of water quality in the Illinois River System.

Following the entry of the United States into the latest litigation concerning the diversion of Lake Michigan water at Chicago, the Department of Justice requested the Public Health Service to furnish such definitive data and information as would be helpful in advancing testimony pertinent to the complex issues before the Court.

Background

The Public Health Service, oldest of the organizations which comprise the Department of Health, Education, and Welfare, is the principal health agency of the Federal Government. Through the Public Health Service, the Government works with the States and with other agencies, both public and private, to discover and apply knowledge that will help to prevent disease, improve health, and promote the public welfare.

Public Health Service studies in water pollution had their beginnings around the turn of the century, following recognition that water-borne diseases were occurring at an alarming rate. By 1910, the first systematic, large-scale investigation of water quality on an area-wide basis was undertaken by the Service. The ensuing half century has brought tremendous strides in the advancement of knowledge, and in expansion of water quality activities in the Public Health Service, leading to the formation in 1960 of the largest and most diversified task force yet assembled to attack the problem in a specific area -- the Great Lakes and Illinois River Basins Project.

The Project, with headquarters at 1819 West Pershing Road, Chicago, is part of the Division of Water Supply and Pollution Control of the Public Health Service. Its permanent staff includes specialists covering a broad gamut of professional skills, including sanitary and hydraulic engineers, chemists, biologists, bacteriologists, radiochemists, oceanographers, and economists. The Project has drawn freely on the resources, human and physical, of the Service's Robert A. Taft Sanitary Engineering Center at Cincinnati, Ohio. Valuable counsel and advice have been received from a Technical Advisory Committee, appointed by the Surgeon General. Membership on this

Committee is composed of men in responsible positions in State water resource and water pollution control agencies, municipal water and sewer departments, private research organizations, conservation groups, and industry. Special assistance has been obtained from other Federal agencies, and through contracts with private consultants.

Purpose

The Great Lakes-Illinois River Basins Project as now programmed has two objectives:

1. To obtain factual data and develop information which the Solicitor General, United States Department of Justice, can introduce as testimony to assist the Special Master in finding the facts of the Lake Michigan Diversion Case.

2. To develop a comprehensive water pollution control program for the Basins, giving due regard to the improvements necessary to conserve the surface and ground waters of the area for all beneficial water uses during the next 50 years, including flow augmentation for water quality control.

Scope

In this report, attention will be concentrated on the first of the objectives stated above. Because the two objectives are closely related, however, much of the material will be common to both.

The physical setting for these reports comprises: Lake Michigan, especially the southern portion; the southwestern corner of the Lake Michigan drainage basin; the main stem of the Illinois River System from its juncture with Lake Michigan at Chicago to its confluence with the Mississippi River at Grafton, Illinois; and land areas abutting and related thereto.

Description of Illinois River System

The Illinois River Basin extends southwesterly across the State of Illinois from Chicago to the Mississippi River at Grafton, Illinois; northerly to a point west of Milwaukee, Wisconsin; and easterly almost to South Bend, Indiana. The natural drainage area totals about 28,200 square miles, divided as follows: 1,000 square miles in Wisconsin, 3,200 square miles in Indiana, and the remaining 24,000 square miles in Illinois. In addition to this natural drainage area, about 810 square miles of Lake Michigan watershed have been made normally tributary to the Illinois River by construction of two diversion canals at Chicago. One of these canals, the Chicago Sanitary and Ship Canal, cuts through the divide to connect the Chicago River, naturally tributary to Lake Michigan, with the Des Plaines River, a tributary of the Illinois River.

The other canal, the Calumet-Sag Canal, connects the Calumet River, tributary to Lake Michigan, with the Sanitary and Ship Canal a short distance upstream from the confluence of that canal with the Des Plaines River.

At the western terminus of the canal system, the Des Plaines River is about 30 feet lower in elevation than the water surface of Lake Michigan; Lockport Dam, at that point, serves both for containment of Lake water and regulation of flows. The flow releases at Lockport are made up of three components: 1) waste water flows representing water withdrawn by pumpage from Lake Michigan for municipal and industrial use and returned to the canal system; 2) the runoff from rainfall on the upstream drainage area; and 3) diversion from Lake Michigan.

The canal system in the Chicago area has three existing inlets, and a fourth potential future connection, from Lake Michigan. The most northerly inlet, at Wilmette, has gated controls at the Lake inlet and connects the Lake via the North Shore Channel with the North Branch of the Chicago River. The central inlet, also gated for control, is at the mouth of the Chicago River. The southernmost inlet is through the Calumet River and Lake Calumet to the Calumet-Sag Canal. Flow control for this inlet is currently provided by the Blue Island Locks at the eastern terminus of the Calumet-Sag Canal. Future control will be accomplished through the new Thomas J. O'Brien Locks, a part of the enlarged navigation channel project now under construction by the Corps of Engineers, Department of the Army. Future plans for navigation facilities call for possible construction of a canal connecting the Calumet-Sag with the Indiana Harbor Canal; such a connection, if made, will constitute a fourth inlet from the Lake to the stream system.

From Lockport downstream to the mouth of the Illinois River, the main stem is a succession of slack-water pools formed by the navigation dams that make it a part of the inland waterway system. Including Lockport, there are seven locks and dams on the system, with lifts ranging from 10 to 40 feet. The waterway was designed and is maintained to provide for vessels having a maximum draft of 9 feet. Heavy siltation has occurred in the pools, with the result that a typical pool consists of shallow overbank areas on each side and a channel portion which is kept clear by a combination of river current, barge traffic, and dredging.

Investigation

The scope of investigations carried out in connection with these studies includes the following:

1. An appraisal of the water resources, presently used and potentially developable, in the area.

2. An inventory of the present uses of the water resource, with quantitative data on the amounts withdrawn for municipal and industrial purposes and the extent of on-site use for other purposes.

3. Identification of sources of pollution, with quantitative data on the amount and nature of water-borne wastes, and the points of discharge to receiving waters of waste residues.

4. Field surveys, including a program of water sample collection in the Lake, in the Chicago area, and downriver; measurement of stream flows associated with sampling; physical observation of field conditions; biological field investigations; and several special field studies as subsequently described herein.

5. Laboratory tests to define the physical, chemical, radiochemical, biological, and bacterial quality of the collected water samples.

Analysis

From the facts gathered in this investigation, the following conclusions are reported herein:

1. The present degree of pollution of surface waters in the area; and

2. The relative magnitude of effects of the several causes of pollution.

II WATER RESOURCES AND USES

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II WATER RESOURCES AND USES

Water Resources

Water resources in the Chicago area and the Illinois River Basin consist of Lake Michigan, the eastern portion of the Little Calumet River watershed tributary to Lake Michigan, the Illinois River and its tributaries, and ground-water supplies. Each of these resources is discussed in the following sections.

Surface Water

Lake Michigan has a surface area of 22,400 square miles and a volume of 1170 cubic miles. The average depth is 276 feet and the maximum depth is 923 feet. It is connected with Lake Huron, which is at the same level, by the Straits of Mackinac. The average flow from Lake Michigan into Lake Huron has been estimated to be about 48,000 cubic feet per second (cfs). (1)

Lake Michigan is replenished by the runoff from 45,500 square miles of land surface tributary to the lake and by an average annual precipitation on the lake surface of about 30.4 inches as estimated from rainfall on surrounding land areas. (2) In addition to the outflow through the Straits of Mackinac, water is diverted at Chicago. This diversion including water supply withdrawal, has averaged about 3250 cfs since January, 1939. Evaporation from the lake surface is estimated from climatological data to average about 28 inches per year. (3)

The average water surface elevation of Lake Michigan is 578.80 feet International Great Lakes Datum. The average annual difference between lowest and highest monthly average lake level is about one foot, with the seasonal high usually occurring in July and the seasonal low usually occurring in February. (2)

The eastern portion of the Little Calumet River watershed, amounting to about 335 square miles, was diverted into Lake Michigan through Burns Ditch in 1926. The average annual runoff of this area is 310 cfs.

The average annual precipitation in the Illinois River Basin is about 34.5 inches, increasing downstream from northeast to southwest. Southeastern Wisconsin has an annual average of 32.7 inches, while at the southern extremity, the area around Grafton has an annual average of 36.3 inches. About 60 per cent of the annual total occurs in the 6-month period April through

September, which includes nearly all of the growing season. December, January, and February are usually the months of lowest precipitation. Long-term records in the basin show annual extremes for the basin of 23 inches and 49 inches of precipitation.

Basin runoff is essentially equal to precipitation on the basin plus diversion and water supply withdrawals at Chicago minus evaporation and transpiration, plus or minus the change in ground-water storage. Evaporation and transpiration are by far the major losses. On the Illinois River Basin, annual evaporation from lakes and reservoirs range from 30 to 36 inches, increasing downstream, with a basin average of 33 inches. About 80 per cent of the evaporation occurs in the months May-October. (3) Total evapotranspiration is about 70-80 per cent of evaporation from free water surfaces. Thus, the average annual water loss is about 25 inches. Runoff, the residual of precipitation minus evapotranspiration, ranges from about 7.5 inches to 10 inches in the basin.

Stream flow increases downstream as augmented by tributary inflow. Figure II-1 shows the average discharge along the main stem of the Illinois River from its origin at the junction of the Des Plaines and Kankakee Rivers to its mouth at Grafton, Illinois. Tributary inflow is shown as a vertical line at the point where a tributary enters the main stem. The average discharge is shown with and without diversion at Chicago. Also shown on Figure II-1 are minimum recorded monthly flows, minimum recorded daily flows on the main stem, and the contributions of the Des Plaines and Kankakee Rivers at their junction.

The Basin is subject to drought and flood conditions. Nearly all of the tributaries with drainage areas less than 1000 square miles have had minimum daily flows near zero. Low flows generally occur in the months July through October.

Ground Water

Ground-water conditions, quality, and availability vary widely over the Illinois River Basin. The Chicago area has large supplies of good water from the deep sandstone artesian aquifers. However, this is becoming inadequate, as general water levels decline as much as 40 feet per year. (4) As a result of this decline with associated increased pumping costs, more use is being made of the shallow Silurian dolomite as an aquifer. Water from the Silurian dolomite is generally hard (100-1000 mg/l) and has more than 0.3 mg/l iron in 80 per cent of samples. (5)

Most of the wells in the Illinois River Basin outside the Chicago area take water from the glacial drift or the first few feet of bedrock below the glacial drift. Deeper drilling into bedrock usually yields water too mineralized for use. Large industrial and municipal supplies are often obtained from buried bedrock valleys which have been filled with coarse material and act either as water-table or artesian aquifers.

Deep bedrock wells in the downstream portion of the Illinois River Basin would doubtless yield large quantities of saline water, and may someday be important.(6) However, at present the glacial drift and the upper bedrock units are the only potential ground-water sources.

In the upstream part of the basin, a buried bedrock valley, the Newark Valley in southeastern and southern Kane and southern DeKalb Counties, appears to be a potential supply of water. The limits and potentials of the valley have not been fully mapped, but the valley may become important. (7)

The Chicago area faces a problem with declining water levels and increasing pumping costs. More efficient use could be made of existing ground-water supplies. For example, much water is pumped to waste by dewatering of stone quarries. This causes large cones of depression in areas of present shortage.(8)

Municipal Water Supplies

Municipal and semipublic water supply data in the Illinois River Basin have been tabulated and summarized by subbasin in Tables II-1 through II-17. The subbasin division of the Illinois River Basin is shown in Figure II-2. Subbasin M16 of Lake Michigan is included since some of the water used in this subbasin can reach the Illinois River System as waste.

The inventory listings include incorporated and unincorporated communities, subdivisions having organized public water systems, institutions, and commercial establishments such as motels.

Surface Water Supplies

The largest single source of municipal water in the Illinois River Basin is Lake Michigan that serves Chicago, Evanston, Wilmette, Skokie, Winnetka, Glencoe, Highland Park, Hammond, Gary-Hobart, Highwood, and the Great Lakes Naval Training Station. These systems also serve many adjoining communities located farther from the lake. All water from Lake Michigan is filtered and disinfected, with exception of the north portion of the Chicago System which is disinfected but not filtered. A new filtration plant is under construction to provide Chicago's North Side with filtered water.

The Illinois River is not used as a source of municipal water supply until it reaches Peoria, Illinois. At Peoria, the supply comes from three sources: conventional ground-water wells, an infiltration gallery with induced recharge from the Illinois River, and a new water plant drawing directly from the River. Depending on river water elevations, Grafton can take its water supply from the Illinois River, from the Mississippi River, or from wells. Other surface water supply sources are located away from the main stem on tributaries of the Illinois River.

In this watershed 5,374,000 persons served by surface water supplies use 1,179 MGD (million gallons daily) or about 220 gallons per capita-day. Surface water sources supply 87 per cent of the water used in the Illinois River Basin and serve 75 per cent of the population. Lake Michigan accounts for 1,121 MGD or 95 per cent of the surface water supplied, serving 4,950,000 persons. Within the Illinois River Basin this accounts for about 69 per cent of the population served from surface and subsurface sources combined.

Ground Water

Almost all communities outside the Chicago Metropolitan area use ground water as a source of municipal water. Several communities in the Chicago area also use ground water sources for water supply.

Ground water sources in the Illinois River Basin serve 1,761,000 persons with 169 MGD which amounts to about 96 gallons per capita-day. Ground water is used by 25 per cent of the population served by municipal supplies, but accounts for only 13 per cent of the volume of water supplied in the basin.

The next section of this chapter states that industrial use of water, other than for power generation, is about 1500 MGD. Total municipal and industrial water use in the basin, other than for power generation, is therefore about 3900 MGD.

Industrial Water Supplies

Industrial establishments in the Illinois River Basin obtain their water from three sources: purchase from public or private water supply, from wells, or from surface sources.

Surface sources provide most of the water used by industry. In 1959, 1.4 billion gallons per day were used for manufacturing and processing. Industries in the Basin that use surface waters are steel and other metals, mining and quarrying, oil refining, chemicals, cement, beverage and food processing, paper and paper products, and railroads. Use of water for power generation will be discussed later.

About one billion gallons per day of surface water are used for manufacturing and processing by industries located in the Upper Illinois River Basin. The Chicago Sanitary and Ship Canal provides 184 MGD to industry. Oil refineries located along the Canal use 123 MGD; the balance is distributed among manufacturing, steel and other metals, and chemical industries. The Calumet River supplies 670 MGD to industry. About 98 per cent of this water is used by the steel industry, and the remaining water is used by manufacturing and chemical industries.

Table II-18 shows the average surface water pumpage from private intakes for the year 1959 in the Illinois portion of the Illinois River Basin.(9)

About 120 million gallons per day of ground water is used by industries located in the Illinois portion of the Illinois River Basin as shown in Table II-19.

The principal water-using industries in the Calumet Area of the Lake Michigan Basin are the steel, petroleum refining, chemical, food processing, and paper products industries. About 2400 MGD are used by 15 industrial plants (Table II-20) that take their water directly or indirectly from Lake Michigan and return it to Lake Michigan.

Navigation

The Illinois Waterway, together with the Chicago River Channel for Deep-Draft Vessels and the Chicago Harbor, provides a navigation channel from Lake Michigan to the Mississippi River. The minimum depth is 21 feet from Chicago Harbor to the Chicago River at Lake Street, and 9 feet from Lake Street to the confluence with the Mississippi River at Grafton, Illinois. These channels are controlled by a series of seven locks and dams operated by the Corps of Engineers. Their navigation capacities are listed in Table II-21.

The Calumet Sag Channel provides a 9-foot depth navigation channel between the Waterway at mile 303.5 above Grafton and Lake Michigan at Calumet Harbor, on the south side of Chicago.

The Illinois Waterway, in addition to serving Chicago and nearby industrial areas in Indiana, also serves several important manufacturing cities along its route including Joliet, Ottawa, LaSalle,and Peoria. It traverses a highly developed agricultural area, and is adjacent to important coal fields. Freight commerce on the waterway has increased since the improved channel to Chicago was opened, from 1,695,000 tons in 1935 to 26,500,000 tons in 1961. The principal commodities are coal, petroleum products, sand, gravel, stone, grain, sulphur, and iron and steel products.

The Corps of Engineers has recommended the construction of duplicate locks for the Illinois Waterway. (10) The proposed locks would be 110 feet wide and 1,200 feet long, compared to the existing lock dimensions of 110 feet by 600 feet. Also under consideration is deepening of the waterway to provide a navigation depth of 12 feet instead of the present depth of 9 feet.

Studies by the Corps have indicated that, with the supplementary locks, the waterway could accommodate the predicted traffic below Lockport of 55,000,000 tons annually by the year 2000. The Corps estimates that an average annual flow of 1,826 cubic feet per second (cfs) would provide the water requirements for the modified waterway at such time as the contemplated traffic develops.

Fish and Wildlife

The following discussion is based on information obtained from the Illinois Natural History Survey; the Illinois Department of Conservation; the Bureau of Sport Fisheries, Department of the Interior; and observations by GLIRBP personnel during field activities during 1961 and 1962. In addition, Project biologists, using electro-fishing gear, determined the kinds and abundance of fishes in the Upper Illinois River System during April, 1961.

Sport Fishing

There is practically no sport fishing in the Upper Illinois River System from the Lake Michigan inlet structures to Dresden Lock and Dam, except for the Kankakee and Des Plaines Rivers. The Kankakee River is reported to support good populations of game fish and is a favored stream of many anglers. The Des Plaines River is not fished heavily.

Downstream from Dresden Lock and Dam only an occasional angler is observed but at Ottawa the numbers increase slightly. The Fox River is fished much more heavily than the Illinois River. More fisherman are noted below the Starved Rock dam; from this point downstream many fishermen are observed, particularly on weekends.

Most of the fishing is from the bank, and the species taken are channel catfish, carp, and buffalo. There is little boat fishing in the Illinois River, probably because of the large numbers of pleasure and commercial craft at all times of the day and night.

Lake Senachwine, near Henry, is the first of many large, shallow (three to four feet deep),flood-plain lakes. Sport fishing for crappies, drum, bluegills, bass, catfish, and carp can be observed at almost any time. Local fishermen sometimes report sizable catches. The fishing pressure is high on the other lakes also, but Rice Lake, downstream from Peoria, and Lake Chautauqua appear to be the ones producing the larger catches. The latter is connected with the Illinois River only during times of flooding.

The Bureau of Sport Fisheries and Wildlife, Department of Interior, manages the Lake Chautauqua wildlife refuge. Lake fishing is monitored by that agency, and creel censuses have been recorded for a number of years. Large catches of game fish are common and fishing pressure is heavy, particularly in the Spring when more than a hundred boats can be seen on the lake at one time.

Commercial Fishing

Commercial fishing pressure parallels sport fishing in the Illinois River. No commercial fishing is observed from the upper river to Dresden Lock and Dam. The Starved Rock Park receives small attention from the commercial fishermen. LaGrange Pool is the most heavily fished stretch of the stream. Considerable activity is observed also in many of the flood-plain lakes.

The Illinois Natural History Survey (11) reported the following statistics on commercial fisheries of the Illinois River Basin during 1950 and 1960:

	1950		1960	
Stream Area	Pounds of Fish	Value	Pounds of Fish	Value
Starved Rock Pool	10,000	$ 700	25,000	$ 4,500
Peoria Pool	2,790,000	106,000	471,000	33,500
LaGrange Pool	2,300,000	136,500	990,000	76,000
Alton Pool	528,000	48,500	636,000	60,000
Totals	5,628,000	$291,700	2,122,000	$174,000

The marketed fish were carp, drum, buffalo, bullhead, and paddlefish.

In 1950, 106 persons earned their entire living by fishing and 196 persons earned a part-time living. By 1960, this decreased to 69 full-time and 73 part-time fishermen. The lower level of commercial fishing activity reflects a multiplicity of causes including economic opportunities, available supply as influenced by species, and market demands.

Wildlife

The many flood-plain lakes of the Illinois River have been famed waterfowl shooting areas for many years. There are more than 300 public and private shooting areas from LaSalle-Peru to LaGrange Lock and Dam, and Chautauqua Wildlife Refuge is an important stopover for thousands of the birds that use the Mississippi Flyway in their migrations. The importance of this resource is difficult to evaluate, but the economy of the area receives a boost from the thousands of hunters who pay as much as $25 per day for a blind at many of the private shooting areas.

There has been a decline in Mississippi Flyway duck population in recent years attributed to the drying up of Canadian potholes and consequent loss of breeding places. There has been a further marked decline in duck population in the lower Illinois River part of the Mississippi Flyway, particularly among the diving ducks that feed on small snails and clams. The flood-plain lakes once were very rich in these small molluscs, but since 1952 investigators have reported diminished population (12).

Biological studies by GLIRBP revealed only sludgeworms and bloodworms where molluscs were plentiful as recently as 1952. This lack of molluscs undoubtedly is one reason that the once plentiful scaup, and other species of diving ducks, avoid the flood-plain lakes in their migrations. Paloumpis et al.believe the lake changes have been caused by pollution and siltation. (12) Investigations by GLIRBP indicate that silt is the pollutant principally responsible for the degradation of these lakes.

Fish Shocking Studies

Although the biological investigations and measures of water quality indicated that very few, if any, fish could exist in most of the stream areas upstream from mile point 300 on the Sanitary and Ship Canal, an effort was made to locate fish with electro-fishing gear that was capable of raising fish nine feet from the probe.

In the North Shore Channel, upstream from the MSD North Side Sewage Treatment Plant, many carp and goldfish were collected and a few shiners, smelts, and minnows. The populations diminished sharply downstream from the sewage treatment plant, and from mile point 322 in the Chicago River to mile point 304 in the Sanitary and Ship Canal no fish were found. A few small carp were taken in the Calumet Sag Channel immediately upstream from the Sanitary and Ship Canal.

Recreation

Within the Illinois River System as previously defined are well-developed water resources that attract millions of recreationally-minded persons. Throughout this entire region are areas of scenic beauty and localities of historic and general interest such as State Parks, memorials, State and County conservation areas, and forest preserves. Such areas are both a regional and a national asset.

The basin provides approximately 60,000 acres of water in sloughs and shallow, flood-plain, backwater lakes flanking the river channel between Spring Valley and Meredosia. These lakes are used for public fishing, boating and swimming, and form the heart of the duck habitat. The river valley provides some of the best mallard shooting in the Nation.

In parts of the Cook County Forest Preserve District, and in the numerous parks along tributary streams, are many water-oriented, recreational attractions which are used for picnicking, boating, water skiing, and angling. Some tributaries are fished, the catch consisting of rough fish such as carp, bullheads, and suckers. These areas are an indispensable part of the larger complex including segments of the vast lake frontage that serves the water-oriented activities in the Metropolitan Region.

The waterway between the Chicago Harbor at Lake Michigan and Joliet is used by pleasure craft principally for transit between Lake Michigan and the Illinois River. Lockages of pleasure craft during 1960 for the seven locks along the Illinois River, as reported to the Corps of Engineers, were 7,839 upbound and 8,586 downbound. In spite of hazards attributable to barge traffic and polluted waters, children have been observed swimming in the canal and water skiers sporting in the waterway.

Many of the pleasures of water-oriented recreation come from the natural beauty usually associated with the water courses. The existence of these natural areas and the continuation of their use for recreational purposes is directly related to the proper use of stream waters and water areas. Water-oriented recreation in the area benefits a large number of communities because the outdoor recreation and tourist industries are important to many local economies. It also enhances community land values by creating a better place to live.

The demand for water-oriented recreation will increase as the population throughout the study area increases.

Irrigation

Average annual precipitation in the Illinois River Basin ranges from 32.7 inches in southeastern Wisconsin to 36.3 inches in the area around Grafton. Localized areas in Indiana and southwestern Illinois have annual averages up to 38 inches. About 60 per cent of the annual precipitation occurs during the crop-growing season.

The sufficiency and timeliness of rainfall, the water-holding capacity of most soils, and the cost of irrigation versus crop returns are reasons why irrigation is not of great importance in Illinois. In 1960 an estimated 5,000 acres were irrigated in the Illinois portion of the Illinois River Basin, of which over half of the acres were irrigated from wells. (13)(14) The greatest density of irrigation is in the Chicago-Kankakee area, including

Cook, Will, and Kankakee Counties. Fields are generally small, averaging about 15 acres. Flowers, nursery plants, and vegetables are the main crops irrigated, and the water here is largely taken from streams and ditches. (14) Some cash-crop and livestock farmers irrigate in the western portion of the Illinois River Basin, in Pike, Adams, Hancock, and Henderson counties. Field crops are irrigated in an area along the Illinois River from Peoria southward, specifically in Peoria, Tazewell, Fulton, and Mason counties. The sandy soils in these areas have the largest potential for future irrigation. (15)

Approximately 6,400 acres are irrigated within the Indiana portion of the Illinois River Basin, primarily in the Kankakee River subbasin. Over 80 per cent of this irrigation is from wells. (13) Corn is the leading irrigated crop both in acreage and dollar value, with hay and forage crops second.

Approximately 400 acres are irrigated in the Wisconsin portion of the Illinois River Basin. (13) Corn is the leading crop in both acreage and dollar value, while planted hay is the second largest crop produced.

The amount of irrigation in the Illinois River Basin is small and not expected to grow rapidly. However, such irrigation as is practiced occurs during dry times when stream flows are small and water tables are low. Some small streams in the Kankakee area are pumped dry at times. (15)

Power

Use of the Illinois River System for hydroelectric power production is limited by the relatively flat topography of the area. The river falls 118 feet in 85 miles from Chicago to Marseilles, and 48 feet in 242 miles from Marseilles to Grafton, yielding few productive sites for hydroelectric power. Two-tenths of one per cent of the power produced in the basin is by hydroelectric plants.

Diverse types of power generation exist within the basin. The Dresden nuclear power plant, at the confluence of the Des Plaines and Kankakee Rivers, is the first full scale power plant constructed for a private concern and financed completely by private funds. In the city of Batavia, on the Fox River, a water wheel produces 20 horsepower for an iron foundry.

Figure II-3, supported by Table II-22, shows the location of existing and proposed power plants.

Most of the power in the basin is generated by thermoelectric (fuel) plants. Plant operating reports are submitted to the Federal Power Commission, but no water use figures are reported. Only the minimum available supply is reported; therefore the column titled, "Estimated Water Pumpage", in Table II-22, has been calculated by assuming condenser pumpage to be one gallon per minute per kilowatt, and considering other uses negligible.

The fuel plants use water for condenser cooling and house service. Condenser cooling uses 95 per cent of the total plant pumpage. House service water is used for bearing cooling, transportation of ash, and housekeeping. The condenser cooling water is taken from the stream upon which the plant is located, given periodic chlorination, passed through the condenser, and returned with a temperature increase of approximately 10°F. The combined estimated pumpage of the 57 fuel plants is 11.3 billion gallons per day or 75 per cent of the 1961 mean flow of the Illinois River as recorded at Meredosia, Illinois.

The combined water requirement of the 11 fuel plants situated along the Illinois River System in the Chicago Metropolitan Area is such that the flow in the system must be used several times. Their total pumpage is 4510 MGD, or 210 per cent of the mean flow as recorded at Lockport. This use of river water increases the stream's temperature significantly. Commonwealth Edison Company reports that increased river temperatures limit the output of the plants during the summer months of July, August and September. The company's four power plants - Fisk, Crawford, Ridgeland, and Will County - experience a total capacity loss of 85,000 kw during periods of high river temperatures. (Table II-23)

Other fuel plants in the basin, such as those of the Illinois Power Company, experience similar limiting conditions during the months of April through October.

Consumptive water uses by the power plants, such as boiler feedwater make-up and house service, are not reported as to quantity or source, but the power companies are interested in holding such uses to a minimum due to the cost of chemical treatment to make the water acceptable for the designated uses.

The present five-year plans for changes for hydroelectric and fuel plants are shown in tables II-24, II-25, II-26 and II-27. Nine proposed hydroelectric plants, if constructed, will increase the hydroelectric generated power by 84,700 kw. Three new fuel plants, and additions minus retirements for existing fuel plants, will increase capacity by 2,870,000 kw and cooling water usage by 6000 MGD. (16)

References

1. *Effect on Great Lakes and St. Lawrence River of an Increase of 1000 Cubic Feet per Second in the Diversion at Chicago.* Division Engineer, North Central Division, Corps of Engineers, U. S. Army (1957).

2. U. S. Lake Survey, Detroit, Michigan (1960).

3. Kohler, M. A., Nordenson, T. S. and Baker, D. R. Evaporation Maps for the United States. *Weather Bureau Technical Paper No. 37*, (1959).

4. Sasman, R. T., Prickett, T. A. and Russell, R. R. *Illinois State Water Circular No. 83*, (1961).

5. Suter, M., Bergstrom, R. E., Smith, H. F., Emrich, G. H., Walton, W. C., and Larson, T. E. *Illinois State Water Survey - Illinois State Geological Survey Cooperative Ground-Water Report No. 1.*, (1959).

6. Source and Occurrence of Brines for Water Flooding in Illinois. Circulars 198, 207, 222, 225, 232 and 238; and Reprint N, Illinois State Geological Survey.

7. Kempton, J. Illinois State Geological Survey, private communication (1962).

8. Walton, William C. Potential Yield of Aquifers and Ground Water Pumpage in the Chicago Region. Illinois State Water Survey unpublished report. Fig. 5.

9. Roberts, W. J. Industrial Water Use in Illinois. *Proceedings of the American Power Conference*, 22: 814 (1960).

10. *Interim Report on Illinois Waterway, Illinois and Indiana.* Corps of Engineers, Chicago District (1957).

11. Starrett, W. C. Illinois Natural History Survey, private communication, (1961).

12. Paloumpis, A. A. and Starrett, W. C. An Ecological Study of the Benthic Organisms in Three Illinois River Flood Plain Lakes. *The American Midland Naturalist*, 64: 432 (1960).

13. United States Census of Agriculture, 1959. U. S. Department of Commerce, Bureau of the Census.

14. Davis, V.W. U. S. Department of Agriculture, Urbana, Illinois, oral communication (1962).

15. Roberts, W. J. Illinois State Water Survey, oral communication (1962).

16. Tower, Kenneth G. Federal Power Commission, Chicago Regional Office, private communication (1962).

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III WATER-BORNE WASTES

This chapter presents an inventory of known wastes discharged to the Illinois River System and is divided into three sections. The first section presents an inventory of municipal wastes, which includes domestic and industrial wastes discharged to municipal sewerage systems. The second section presents an inventory of industrial wastes discharged directly to local water courses. The third section discusses special investigations of sewer outfalls.

The sewage and industrial waste loads discharged to the Illinois River System are depicted in Figure III-1. They are summarized as follows:

Municipal Wastes	1,446,000 PE*
Industrial Wastes	971,000 PE
Total	2,417,000 PE

Municipal Wastes

Sewered communities, institutions, and commercial establishments such as motels are included in the municipal sewage inventory for the Illinois River Basin. Inventory data were compiled from existing Federal, State, Local and Sanitary District reports and supplemented by field investigations. The reported data are for the year 1960, except that data for Subbasin M16 are for the year 1961. Subbasin M16, which is tributary to and at the south end of Lake Michigan, has been included in a separate tabulation but not added to the totals for the Illinois River Basin. This Subbasin has been included because there is no physical divide on the Grand Calumet River between M16 and the Illinois River Basin. Therefore, during and after intense rainfall the water surface in the Grand Calumet River can rise high enough to induce flow out of Subbasin M16 into the Illinois River Basin.

The Illinois River Basin was divided into 15 subbasins for tabulation (See Figure II-2). Systems serving 1000 or more persons are tabulated individually with identification of the receiving stream, mileage from the mouth of the stream to the point of discharge, degree of treatment, population connected to sewers, and population equivalents of the untreated and discharged waste.

Population equivalents (PE) are calculated on a 5-day biochemical oxygen demand (BOD) basis, using analytical data furnished by the plant or control agency and assuming each pound of BOD to be equivalent to six persons. Where industrial wastes of consequence, from a BOD standpoint, contribute to municipal sewage, the population equivalent of the combined waste can usually be expected to exceed the population connected. The population equivalent untreated was observed to be larger than the population connected in communities where industrial contributions are large, such as Chicago. In some communities with little or no industry, the population connected figures exceed the computed population equivalent. Investigations of a few such cases revealed the communities to be predominantly residential areas on the fringe of Chicago or other metropolitan areas.

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* Population Equivalent

Systems serving less than 1,000 persons are grouped in the tables by degree of treatment. These are shown below the individual listings of larger waste loads. Where analytical data were not available, engineering estimates were made of the waste loading based on 85 per cent reduction for secondary treatment and 35 per cent for primary treatment.

Table III-1 is a summary table showing waste loadings in the entire Illinois River Basin. Figures III-2, III-3, and III-4, show locations and individual loadings of municipal waste discharges.

Table III-2 is a tabulation of data for the North Branch Chicago River Subbasin, Subbasin 1. All communities in this Subbasin provide secondary treatment except a trailer park which has septic tanks. The municipal waste in Subbasin 1 is 1,128,000 PE before treatment and 56,000 PE after treatment. This represents an overall reduction of 95 per cent. About 87 per cent of the discharged load is contributed by the North Side Treatment Plant of the Metropolitan Sanitary District of Greater Chicago (MSD).

Information regarding the main channel of the Illinois River System, Subbasin 2, is shown in Table III-3. The municipal waste in this Subbasin is 6,416,000 PE before treatment and 713,000 PE after treatment. This represents an overall reduction of 89 per cent. About 98 per cent of this load is contributed by the West-Southwest Plant of the MSD and by the city of Joliet, with the MSD plant accounting for over 91 per cent of the total load.

Data on the Calumet Sag Channel and Tributaries, Subbasin 3, are shown in Table III-4. The municipal waste in Subbasin 3 is 1,163,000 PE before treatment and 182,000 PE after treatment. This represents an overall reduction of 85 per cent. The Calumet Sewage Treatment Plant of the MSD contributes 53 per cent of the load, and the city of Hammond, Indiana contributes 23 per cent.

Subbasins 4, 5, 6, and 7 are residental suburbs in the Chicago Metropolitan area. The municipal wastes in these four Subbasins is 796,000 PE before treatment and 202,000 PE after treatment. This represents an overall reduction of 75 per cent.

The waste load discharged to the Des Plaines River Subbasin, Subbasin 4, in Cook County is relatively small when the drainage area and the population within the Subbasin are considered. This area is served by an interceptor sewer, paralleling the Des Plaines River, which collects the municipal waste for treatment at the West-Southwest Treatment Plant of the MSD. Therefore, a small part of the population in Subbasin 4 contributes waste to the Des Plaines River; most of the waste is contributed to Subbasin 2. The areas served by the interceptor appear in a footnote to the West-Southwest Treatment Plant data shown in Table III-3.

Subbasins 1 through 7, which include Chicago and the surrounding metropolitan area, account for 88 per cent of the sewered population in the Illinois River Basin. The waste from these Subbasins amounts to 9,503,000 PE before treatment and 1,153,000 PE after treatment, indicating a reduction of 88 per cent. The other Subbasins, 8 through 15, are predominantly agricultural areas. Waste sources in these Subbasins are primarily small rural communities, and a relatively small number discharge waste to local watercourses. Many communities in these Subbasins are served by septic tanks with or without subsurface disposal facilities. However, in several communities there are unofficial tile "sewer" systems that are directly connected with septic tanks and discharge to local watercourses.

The municipal waste load in Subbasins 8 through 15 is 1,058,000 PE before treatment and 293,000 PE after treatment, indicating a net reduction of 75 per cent.

The data presented in Table III-1 summarizes the 15 Subbasins of the Illinois River System and shows that 678 communities, institutions, and commercial establishments are served by 573 sewage works. The total waste load to these works is 10,561,000 PE and the load discharged to the Illinois River System after treatment is 1,446,000 PE. Of the 573 sewage works included in this inventory, 32 per cent provide little or no treatment, 5 per cent primary treatment, and 63 per cent secondary treatment.

The three principal treatment plants of the MSD serve approximately 69 per cent of the sewered population in the Basin and receive 76 per cent of the connected PE. They account for approximately 53 per cent of the total load discharged. These data indicate that the MSD treats more waste than the rest of the Basin and provides a greater degree of treatment.

In addition to sewered or partially sewered communities included in this inventory, there are many unsewered areas served by septic tanks which discharge septic tank effluent or raw sewage to local watercourses. There may be some cases where the overall waste contribution to a local watercourse is considerable, but in general these are matters of local sanitation.

Industrial Wastes

The industrial waste inventory presented in this section encompasses industrial establishments that discharge directly to the receiving waters of the area.

Initial waste loads were compiled from State, County, City, and Sanitary District records, and supplemented by data received from individual industries, regulatory agencies, and field investigation of known outfalls. For some industries, waste loads were estimated from data obtained from similar industries.

Industries discharging waste loads of 1,000 PE or greater are tabulated individually for each Subbasin in Table III-19, and depicted in Figures III-5 and III-6. Industries that discharge waste loads of less than 1,000 PE are grouped for each Subbasin.

The Public Health Service inspected 54 of the industries jointly with representatives of the Illinois State Sanitary Water Board or the Metropolitan Sanitary District of Greater Chicago. The majority of the industries inspected provided waste treatment facilities and/or control measures (Table III-18).

The following industries are the principal sources of industrial pollution in the Illinois River System: textile, food and kindred products, petroleum, pulp and paper, and chemicals and allied products. The industrial waste load discharged directly to the Illinois River System is 971,000 PE (Table III-19). The load for each Subbasin is summarized as follows:

Subbasin	No. of Plants	Population Equivalent
North Branch Chicago River	13	16,300
Illinois River System & Minor Tributaries - Lake Michigan to Kankakee River	42	387,100
Calumet Sag Channel & Tributaries	35	87,700
Des Plaines River	14	4,000
Du Page River	12	2,000
Kankakee River	10	14,000
Fox River	21	19,700
Vermilion River	3	600
Mackinaw River	1	1,000
Spoon River	2	300
Sangamon River	11	11,500
Illinois River System & Minor Tributaries - Kankakee River to Spoon River	19	426,900
Total	183	971,000

The records of the MSD were studied to determine the amount and type of industrial wastes discharged directly to the river system within the boundaries of the Sanitary District. The MSD has studied industrial effluents for the past 30 years and has conducted more than 900 separate investigations. Twenty-eight industrial plants were inspected jointly by the Public Health Service and the MSD. Manufacturing methods and estimated waste loads in all but three plants were found to be essentially as reported by the MSD. The information regarding manufacturing methods and waste control facilities at these three plants was found to be out of date.

The Illinois River System was last studied comprehensively by the Public Health Service in 1921-1922, and the industrial waste load discharged directly was estimated to be 1,885,600 PE in the Metropolitan Chicago area drained by the Illinois River and the North Branch of the Chicago River, but excluding the Calumet and Des Plaines Rivers. The estimated industrial waste load in 1960 to the same section of the river system is 224,900 PE or only 12 per cent of the 1921-1922 load. This decrease has been accomplished principally by collecting the waste in new interceptor sewers and by construction of new and enlarged treatment works.

The total known industrial waste load discharged to the river system in the Chicago area outside of the MSD is 25,300 PE. Industries located within the MSD discharge 5400 PE directly to Lake Michigan. These industries are included in Lake Michigan Subbasin M16.

Many industries discharge wastes that adversely affect the waters of the Illinois River System in ways other than depressing the dissolved oxygen concentration. A partial list of these pollutants is as follows: heat, inert solids, oil,and dissolved inorganic chemicals.

The industrial waste load discharged to the Illinois River System in the Peoria-Pekin area is estimated to be 386,000 PE. This load was obtained from the examination of State, local, and industrial records and was substantiated by field investigations. This load is discharged principally from 13 plants and is equivalent to approximately eight times the amount of the treated domestic sewage from this area.

Downstream from the Peoria-Pekin area to the confluence of the Illinois River with the Mississippi River there are no reported industrial waste loads of any significance. State and local records indicate there are approximately 500 minor industries that discharge to streams. These industries are locker plants, coin laundries, and metal fabricators. Sixty per cent of these industries do not create a problem in the disposal of their wastes. The other industries create minor local nuisances.

The Lake Michigan Subbasin M16 contains a concentration of large, basic manufacturing industries that use large volumes of process and cooling water. A summary of the wastes from these industries is shown in Table III-20.

Miscellaneous Sewer Outfalls

There are numerous sewer outfalls visible along the banks of the Illinois River System. Most of these outfalls are storm sewers or storm relief sewers. A lesser number of outfalls are industrial sewers discharging liquid wastes to the river system. The outfalls in the Chicago area and the Peoria-Pekin area were investigated in two separate investigations to verify or supplement known industrial waste loads.

Chicago Area

This study covered the North Shore Channel, North Branch Chicago River, Chicago River, South Branch Chicago River, Calumet River, Grand Calumet River, Little Calumet River, Calumet Sag Channel, and the Sanitary and Ship Canal above Romeoville. Outfalls from sewage treatment plants and electric generating stations were not sampled. The existence of submerged outfalls was not determined during this study.

A preliminary reconnaissance of the area was made and grab samples were taken from all outfalls with an estimated flow of three gallons per minute (gpm) or greater. The flow was estimated by standard hydraulic field methods. In most instances it was possible to trace the waste to its source.

More than 400 outfalls were observed during the preliminary reconnaissance, of which 105 discharged BOD loads in excess of five pounds per day and were considered significant. These latter were sampled once daily on three different days and at different times during an eight-hour period. The individual loadings were computed from the analytical results and the flows observed during the eight-hour period. These were extrapolated to 24 hours by considering the type of industry and operating hours.

The results of this study are recorded in Table III-21 and are grouped according to the river sampling stations as recorded in Chapter IV. The column titled "Net Population Equivalent" (Net PE) shows the loading corrected for the quality of river water, if used by the industry as a water supply. The column titled "Estimated PE, 24-hour" shows the extrapolation of the eight-hour observations to the 24-hour loading.

The total extrapolated population equivalent discharged to the river system from the 105 outfalls investigated is 370,000 PE. Approximately 75 per cent of this load has been accounted for in the industrial waste inventory. The remaining 25 per cent of this load is in addition to the municipal and industrial waste inventory. This additional waste load is primarily from storm relief sewers that were observed to be flowing during dry weather and outfalls from unidentified sources.

Peoria-Pekin Area

This portion of the outfall sewer study covered the Illinois River from approximately Mile 143 to Mile 166, and includes the industrial complex of the Peoria-Pekin area. Forty-three separate outfalls were investigated during this study.

The outfalls were studied over a nine-day period, and each outfall was investigated at least once each day. A grab sample was collected and the rate of flow was estimated by standard hydraulic field methods each time the outfall was observed. Outfalls which were discharging larger flows were investigated twice on some days.

Table III-22 presents a summary of this survey. Of the 43 outfalls only 27 were considered as contributing a significant BOD load to the Illinois River in the Peoria-Pekin area. This survey indicates that the estimated BOD load discharged to the Illinois River from industrial sources is 386,000 PE, and that approximately 50 per cent of this load is contributed by one source.

IV FIELD INVESTIGATIONS

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FIELD INVESTIGATIONS

The numerous and varied techniques required to obtain suitable samples for physical, chemical and biological laboratory studies are discussed in this chapter.

Also considered are such related projects as: carbon filter studies, continuous dissolved oxygen (DO) recording, the physical appearances of waterways from which samples are obtained, and hydrography.

Sampling Locations and Times

The sampling locations utilized in the study of the Illinois River Basin system are presented in Figures IV-1, 2 and 3. Tables IV-1a, 1b, 1c, 1d, 1e, 1f, 1g and 1h contain a complete description of all the sampling stations.

The station designations consist of two capital letters as abbreviations for the named streams and a numerical representation of the river mileage to that point from Grafton, Illinois, the zero mile point of the Illinois River system.

The sampling period began in April, 1961, and continued through August, 1962. In this period, the Upper Illinois River system was studied for five separate monthly periods, the Calumet-Little Calumet system tributary to the Upper River system was studied for one month and the Lower Illinois River and its major tributaries for three months. The dates of sampling periods, and the number of days sampled at each location are tabulated below.

Location	Sampling Period		Days Sampled
Upper Illinois River System	April-May,	1961	26
" "	June,	1961	22
" "	July,	1961	18
" "	August,	1961	16
" "	Jan.-Feb.,	1962	24
Calumet-Little Calumet	Feb.-March,	1962	20
Lower Illinois River System	Nov.-Dec.,	1961	21
" "	March-April,	1962	27
" "	July-August,	1962	31

Eighty-three stations were occupied along the entire river and its tributaries. Stations were selected at closer intervals in the upper river, the stretch above the Dresden Island Dam, to provide a more intensive study of the effects of the many waste discharges in this region.

In the lower river, the stations were located at less frequent intervals. Their location was chosen chiefly to study the effects of the major tributaries and the navigational pools as well as major sources of waste discharge on the main stream.

Sample Collection Procedures

A variety of sampling procedures were employed in order to obtain suitable specimens for such diverse studies as: bacteriological content; biological content; chemical, physical and radiochemical studies. These sampling procedures took into account such necessary precautions as proper preservation of samples until such times as laboratory experiments could be performed.

Bacteriological

Coliform and fecal streptococcus samples were collected in sterile glass bottles at the surface of the stream.

Enterobacteria and virus samples were collected by the Moore gauze pad technique, which is described in Chapter VII under Special Investigations.

Chemical, Physical, and Radiochemical

Dissolved oxygen samples were collected with the sampler described on p. 308 of Standard Methods (1). This sampler is necessary to protect the collected sample from exposure to atmospheric oxygen. These samples were collected at middepth and at midpoint in the main channel of the stream, unless otherwise noted.

Samples for other physical and chemical tests were collected and transferred to separate polyethylene bottles under the same conditions described for the dissolved oxygen sample. The temperature of the water was taken at the time of sample collection by immersion of a calibrated thermometer into the water collected by the sampling device.

Biological

Samples for plankton and algae were collected from the surface of the stream and preserved with 4% formalin. Attached algae were collected from surfaces such as pilings, piers and other points of attachment. Benthic samples were collected with the Eckman or Petersen dredges, which are described in Standard Methods on p. 574.

Sample Preservation

All bacteriological samples (as well as DO and BOD samples) were delivered to the laboratory for analysis within four hours of the time of collection. Preservation was accomplished by icing the samples from the time they were collected until brought to the laboratory.

Plankton samples were preserved with formalin (4% formaldehyde).

The Moore gauze virus pads were preserved by icing.

Verification of Sampling Procedures

A number of special investigations were made to assure the adequacy of sampling stations, sampling procedures and analytical results, and to assist in the ultimate interpretation of data.

Stratification was one problem. The entrance of cool lake water into the warmer canal waters led to the belief that the cooler lake water might flow along the bottom of the river for significant distances before mixing. Also, it was believed there might be thermal stratification below points of discharge of cooling water from steam power plants.

Therefore, temperatures were determined at various depths at selected stations throughout the river system before routine sampling was initiated. No significant thermal stratification was observed.

The possibility of diurnal DO variations had to be considered. In many surface waters photosynthetic production of oxygen by algae leads to considerable variation in DO; DO may be high in daylight and relatively low during periods of darkness.

Nighttime determinations of dissolved oxygen were made at all stations on the upper waterway on three separate occasions; the results were compared with DO data obtained during normal daytime sampling periods. The comparisons indicated that variability in DO, attributable to photosynthesis, was not significant during the study period.

The preservation of samples during the interval between field collection and laboratory analysis required study. These studies led to the use of preservation techniques already discussed.

Carbon Filter Studies

Standard carbon filter installations (see Chapter V, Organics Investigations) were made at the Wilmette Inlet and the Lockport Dam. The filters were changed every seven days.

Continuous DO Recording

Continuous dissolved oxygen recordings were taken with Hays DO analyzers at three locations. One was located at milepoint NS 340.7 on the North Shore Channel in Wilmette, Illinois, a point of diversion of Lake Michigan into the Illinois Waterway system. The second was placed above the dam on the Chicago Sanitary and Ship Canal at milepoint SS 291.2 in Lockport, Illinois. Lockport is the main control point of the diverted flow in the canal and this station monitors the oxygen content of the water as it leaves the Chicago urban area. The third station is also in the Lower River. It was situated at milepoint IR 157.7 above the dam at Peoria, the largest city on the Lower River.

Physical Appearance of Waterways

During the routine collection of samples at the various stations described, the sample collector observed the physical appearance of the waterway at the time of sample collection. These observations were recorded on appropriate forms provided for this purpose. A copy of this form is presented as Figure IV-4.

The results of these observations are summarized in Tables IV-2a, 2b, 2c and 2d. The tables summarize, under remarks, the observations that were noted at more than 50 percent of the visits to the station listed.

From the Wilmette Diversion Inlet at river mile 340 to the entrance of the North Side Sewage Treatment Plant at river mile 336.6, the waterway appeared relatively clean. Beyond this point, however, to the junction of the Sanitary and Ship Canal and the Cal Sag Channel at river mile 303.4, the condition of the river changed drastically. Rubbish, garbage, oil slicks and other floating debris were observed throughout this section of the river. Also, gases of decomposition were seen bubbling to the surface.

The Calumet, Grand Calumet, and Little Calumet Rivers were observed to be generously littered with rubbish and exhibited large amounts of oil. This condition also existed throughout the Cal Sag Channel to its junction with the Sanitary and Ship Canal.

The continuation of the Sanitary and Ship Canal below the confluence with the Cal Sag Channel exhibited the characteristics (gas bubbles, rubbish, garbage and oil slicks) of both the Cal Sag and its own previous section. This condition extended downstream to the confluence with the DesPlaines River, river mile 290. The DesPlaines River, above the junction, exhibited a lesser amount of floating debris. Foam covered many sections of the river, however. Below the junction, the gas bubbles disappeared but rubbish and garbage remained. At the confluence with the DuPage and Kankakee River, river mile 277 and 273 respectively, the floating debris increased sharply. From this point in the Illinois River to the confluence of the Fox River at river mile 241.1, the oil slick and debris decreased, but foam and aquatic vegetation began to appear. Beyond this point, the foam and vegetation decreased and finally disappeared about mile 210. The Vermillion River, entering 40 miles downstream, introduced a small amount of foam and rubbish to the waterway.

The remainder of the Illinois River to the Mississippi River was comparatively clean. Six tributaries - Kickapoo Creek (river mile 159), the Mackinaw River (river mile 148), the Spoon River (river mile 120), the Sangamon River (river mile 98), the LaMoine River (river mile 84), and Macoupin Creek (river mile 23) were the last major streams to enter the waterway and none introduced more than a slight amount of rubbish.

Hydrography

Rather extensive measurements of stream flow were necessary in the Chicago area because no regular gaging stations are operated on the canal system. The United States Geological Survey maintains gaging stations on several of the tributary streams, and publishes daily flows for the Sanitary Canal at Lockport which are computed and furnished by the Sanitary District.

Flow computations for the lower Illinois River were based on flows derived from U. S. Geological Survey gaging stations on the main stem and tributaries. High water during the March-April, 1962, sampling period greatly complicated the flow calculations, because of the large storage areas in the lower river valley.

Hydraulic Measurements and Computations for the Chicago Area

Hydraulic data required for each day of the sampling period in the Chicago area were:

1. Average flow at each sampling point.
2. Average flow of each major tributary.
3. Average depth of each reach between sampling stations.
4. Average velocity of flow in each reach.
5. Time of water travel in each reach.

Daily Flows

Flow data normally available from the Sanitary District include daily flows at Lockport, inflows from Lake Michigan at Wilmette (North Shore Channel), at mouth of Chicago River, and at Blue Island Controlling Works on Calumet Sag Channel; discharges from the storm-water pumping stations on the canals; and discharges from the three major treatment works. During the sampling periods, the Sanitary District furnished, in addition to the data listed above, daily estimates of discharge for: North Shore Channel at Foster Avenue; North Branch of Chicago River at Kinzie Street; South Branch of Chicago River at Lake Street; Sanitary and Ship Canal at Harlem Avenue; and Calumet Sag Channel at Sag Junction.

In order to obtain measured flows to augment the data furnished by the Sanitary District, a contract was entered into with the United States Geological Survey, Champaign, Illinois, for daily discharge measurements during the first sampling period at each of the following stations:

North Branch of Chicago River at Montrose Ave., Chicago, Ill.

Sanitary and Ship Canal at Wentworth Ave., Willow Springs, Ill.

Calumet Sag Channel at Harlem Ave., Palos Heights, Ill.

Discharge measurements were made by Project personnel at the same locations during subsequent sampling periods.

Daily flows at U. S. Geological Survey gaging stations on nine tributaries were determined from gage readings obtained from the Survey or by Project personnel in the field.

Daily flows at sampling points were based on routings of the daily flows for the locations noted above.

In general, flow rates were fairly constant throughout the sampling periods in the Chicago area, with only minor day to day fluctuations due to changes in regulation by the Sanitary District. An exception was the January 1962 sampling period when the District made a number of operational changes which increased or decreased the daily flow at Lockport as much as 1,000 cubic feet per second (cfs). On three occasions excessive rainfall caused major increases in rates of flow. These occurred on April 24, August 1, and August 4, and in each instance resulted in a daily flow at Lockport of about 6,000 cfs, or almost twice the normal average discharge.

Average Water Depths

All available cross-sections for the reaches between sampling points were assembled from the Corps of Engineers, Chicago District, and from the Sanitary District. Average cross-sectional areas, top widths and water depths were determined for each reach for a control water elevation. From these data the average depth for each reach for the water elevation occurring on each day was determined from gage heights supplied by the Sanitary District.

Times of Water Travel

Several of the reactions involved in natural purification of streams are functions of time. Full understanding and interpretation of stream data are possible only if the times required for the water to pass between pertinent points are known. Average discharges for each reach were computed from the discharges at the sampling points. Average velocity for each reach was computed from average discharge and average cross-sectional area. Time of water travel was then obtained by dividing length of reach by average velocity.

Hydraulic Measurements and Computations for the Lower Illinois River

Average monthly discharges were required at the sampling points on the main stem, and on the major tributaries. During the March-April 1962 sampling period, the river was in flood and average discharges were computed for two 16-day periods approximating the rising and falling phases of the flood. During the November-December 1961 and the July-August 1962 periods the river was at pool stage.

Tributary Flows

Daily flows of the tributaries were determined from once-daily gage readings. These gage readings were obtained from the Corps of Engineers, the U. S. Geological Survey, the Sanitary District, and Project personnel in the field.

Main Stem Flows

Daily flows were obtained at three points; Marseilles, Kingston Mines, and Meredosia. These flows were obtained from daily Corps of Engineers gage readings.

Storage Capacity

During the March-April 1962 period it was necessary to know the storage capacity of the river and flood plain, inasmuch as the river stage was considerably higher at the end of the sampling period than at the start. This capacity was derived from topographic maps contained in the Corps of Engineers' report on the Illinois River.

Drainage Area

The total drainage areas of the tributaries and local runoff areas were taken from a drainage map of Illinois prepared by the Division of Waterways, State of Illinois.

In computing the average daily flows for the March-April sampling period the following method was used. The main stem was divided into reaches. Each reach consisted of the length of river between sampling points, or between a sampling point and the junction of the Illinois River with a tributary.

In general, the daily flows for each sampling point were computed downstream from a gaging station, starting with the observed discharge and adding the local runoff and the change in storage, the local runoff and storage being calculated according to the length of the reach. This total was assumed to be the flow at the downstream end of the reach. At the lower end of the river, it was also necessary to work upstream from the gaging station. If the end of the reach was just upstream from the junction of a tributary, the flow of the tributary was added to make the total flow at the start of the new reach. The average flow for a reach was assumed to be the average of the flows at the beginning and ending of each reach.

In order to compute flow times between the sampling stations, it was necessary to determine cross-sectional areas corresponding to various river elevations. The Corps of Engineers furnished sounding and contour maps of the Illinois River. From this information, curves could be drawn of area versus elevation. These area-elevation curves were determined for cross-sections approximately two miles apart, between Dresden Island Dam (mile 271.6) and mile 223.0. Below mile 223.0, the Corps of Engineers furnished area-elevation curves and flow distribution curves for sections taken approximately every two miles. The flow distribution curves show the channel flow as a percent of the total flow at any river elevation.

The cross-sectional area used was the total of the channel area and the overbank area, if any. An exception was the stretch from mile 223.0 to Lake Peoria (mile 179.0). In this stretch, the river flows through a number of small lakes and sloughs, so that the channel is not well defined. The areas in this stretch were obtained by dividing the channel area by the flow distribution. This gives an area that can be used in conjunction with the total flow.

It was recognized that during flood stage (March-April 1962 sampling period) the overbank velocity would be lower than the channel velocity. However, except for that portion upstream from Lake Peoria mentioned above, it was not considered practicable to subdivide the total area into channel and overbank areas, which would have required detailed water surface profile computations. Preliminary investigations indicated that the refinement of results obtained would not justify the time and manpower required.

The final objective was to determine a curve of average stage versus average cross-sectional area for each reach. This curve was determined as a weighted average of the area-elevation curves developed at each cross-section. From these final curves the average stage for each reach, obtained from profiles based on daily gage heights, could be used to obtain the average cross-sectional area for the reach.

Similar curves were determined for the reaches from the sampling points on the tributary streams to the junction with the Illinois River.

From these daily flows and cross-sections, velocities and travel times were developed for the reaches and river as a whole.

For the November-December 1961 and the July-August 1962 periods, when the river was at pool stage, average travel times were developed, based on mean monthly flows and channel areas at pool stage,

A summary of the flow and travel time computations will be presented in Chapter IX of this report, in conjunction with quantitative calculations of stream loadings.

References

1. Standard Methods for the Examination of Water and Waste Water, 11th Edition, 1960. American Public Health Association, American Water Works Association, Water Pollution Control Federation.

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V PHYSICAL AND CHEMICAL INVESTIGATIONS

Introduction

This chapter presents the physical and chemical results obtained from stations on the Illinois River System and major tributaries during the period April 1961 through August 1962. The data are grouped by sampling periods, as described in Chapter IV, and presented as algebraic averages of the individual values obtained, unless otherwise designated. The parameters measured and reported in subsequent sections of this chapter are: Temperature; Hydrogen Ion Concentration (pH); Dissolved Oxygen (DO); Biochemical Oxygen Demand (BOD); Chemical Oxygen Demand (COD); Dissolved Solids; Suspended Solids; Chloride; Alkyl Benzene Sulfonate (ABS); Phosphate; Ammonia, Organic and Nitrite plus Nitrate Nitrogen; Toxic Metals including Cadmium, Chromium, Copper, Nickel and Zinc; Organic Contaminants; and Radioactivity. Each of these parameters is defined in the respective sections of this report.

Laboratory Procedures

Analytical determinations were made at the laboratories of the Great Lakes-Illinois River Basins Project; at 5555 South Archer through July, 1961, and at 1819 Pershing Road, Chicago, Illinois, after August 1, 1961. During the periods of study of the Lower Illinois River, a field laboratory was established at the Peoria, Illinois, office of the Illinois Water Survey. This laboratory performed the physical, bacteriological and chemical analyses requiring immediate attention.

In the earlier periods of this study, the principal laboratory effort was expended on the measurement of the parameters of gross pollution such as dissolved oxygen, biochemical oxygen demand, temperature and pH. As laboratory capability developed, additional parameters were included in order that other factors affecting water quality could be evaluated.

Analytical Methods

The chemical data included in this report were obtained, unless otherwise indicated, by using the procedures published in "Standard Methods for the Examination of Water and Wastewater, 11th Edition, 1960", hereinafter referred to as "Standard Methods." While many methods may be used in water analysis, those described in the "Standard Methods" were selected by the Public Health Service because the procedures are supported by collaborative studies of capable analysts, throughout the nation, who have demonstrated the methods to be sufficiently accurate and reproducible.

Minor modifications were made by this laboratory in certain procedures, when in the judgment of the Chief Chemist, they could better accomplish the purpose for which the procedure was applied. Before adopting any changes or modifications, however, many analyses were repeated to determine the precision and accuracy of the modified method and also the agreement with the "Standard Method."

To assure continually reliable data, reference standards of known composition were analyzed daily in conjunction with each test. Blanks were analyzed simultaneously with all tests. The glucose-glutamic acid synthetic standard was used to determine the accuracy and precision in the BOD tests.

A skeleton outline of tests performed by this laboratory follows. Where the tests conform strictly to "Standard Methods", only the pages wherein the procedure may be found are cited, but where modifications or changes are made these are described in detail.

1. Hydrogen Ion Concentration (pH)

This test was performed by the Glass Electrode Method as described in "Standard Methods" on page 194.

2. Dissolved Oxygen

This test was performed in accordance with procedure described in "Standard Methods", Method A, Alsterberg (Azide) Modification of the Winkler Method, pages 309-311.

3. Biochemical Oxygen Demand

The procedure for Biochemical Oxygen Demand was the same as described on pages 318-23 in "Standard Methods."

4. Oxygen Demand (Chemical)

The method used was as recommended in "Standard Methods," pages 399-402; but without silver sulfate. The chloride correction was applied to each test result.

5. Nitrogen. - Ammonia and Organic

Free Ammonia Nitrogen was quantitatively determined by the distillation method described in "Standard Methods," pages 298-299. Organic nitrogen was measured by the Kjeldahl method using mercuric sulfate as a catalyst. This procedure is described in "Standard Methods," pages 305-307.

6. Nitrate and Nitrite Nitrogen

Nitrogen in the form of nitrates was determined by the phenoldisulfonic acid method described in "Standard Methods", pages 302-303. The nitrites, if present, were oxidized to nitrates with hydrogen peroxide (H_2O_2) in acid medium.

7. Chloride

Chloride content was measured by the mercuric nitrate method described in "Standard Methods", on pages 79-81.

8. Solids

Suspended and dissolved solids were measured by the method described in "Standard Methods", pages 326-330.

9. Alkyl-Benzene Sulfonates

The methylene blue procedure for determining Alkyl-Benzene Sulfonate (ABS) as described in "Standard Methods", pages 245-251, was modified by this laboratory. The changes in no way affected the reproducibility or accuracy of the method, but did speed up the procedure and economize on the use of time and reagents.

The modifications were as follows:

(a) The washing of extracts with wash solution was eliminated because comparative studies showed that values were equally reproducible and accurate without this step.

(b) Twenty-five ml aliquots or aliquots diluted to 25 ml were used for analysis.

(c) Five ml of methylene blue solution was added to each sample. An additional amount, if needed, would be indicated by the water phase becoming clear after extraction with chloroform.

(d) The sample was extracted two times with 10 ml portions of chloroform and filtered through a plaget of cotton in the tip of the separatory funnel. This filtered and removed moisture from the chloroform extract satisfactorily.

(e) The sample was collected, made up to volume and read in the spectrophotometer at a wave-length of 650 milli-microns.

10. Metals (Toxic)

A polarographic technique was used to analyze water for toxic metals. The instrument selected was the Sargent Model XV because of its great sensitivity. Metals in concentrations as low as 0.01 mg/l can be determined and, with the addition of the range extender and/or greater concentration of sample, lower levels may be detected.

The method has been demonstrated to be as accurate as, and definitely more time-saving than, the usual colorimetric procedures. The precision was in the range of ± 3%, and accuracy determined was ± 5%.

A detailed description of procedure is as follows:

I. APPARATUS

1. Sargent Model XV Recording Polarograph.
2. Micro Range Extender for above.
3. 500 ml Graduated cylinders.
4. Funnels for above.
5. Muffle Furnace.
6. Pipettes (Mohr + volumetric).
7. 10 ml beakers.
8. Hot plate.
9. 50 ml volumetric flask.
10. Folded filter paper.

II. REAGENTS, Not mentioned in Procedures

1. Mercury (high grade metal-free)
2. Nitric-acid (conc)(metal-free)
3. Hydrochloric acid (conc)(metal-free)
4. Double distilled water (metal-free)
5. Sodium Sulfite (used to wash nitrogen)
6. Bottled Nitrogen Gas (water pumped)

III. PREPARATION OF SAMPLE

Wash all glassware and other containers with HNO_3 (1:1) and rinse with re-distilled water.

Avoid etched beakers, because they could conceivably retain metals.

To prevent adsorption of metals on the walls of the container, add 5 ml of HNO_3 (conc.) per liter of sample, as soon as possible after sample is taken.

To a 500 ml filtered sample in a 600 ml beaker, add 1 ml NaOH (2N) and 5 ml HNO_3 (conc.). The NaOH provides bulk to prevent loss of metals in subsequent ashing.

Evaporate the sample to dryness at a temperature just below boiling to prevent splattering.

Ash the sample contained in the beaker in a muffle furnace at 450°--500° for 15-20 minutes. If carbon is still present (by dark color of sample), add additional nitric acid, redry the sample and re-ash.

After cooling, add a mixture of 5 ml HCl (1:1) and 5 ml HNO_3 (1:1), cover with watch glass, and heat gently for 10 minutes.

Dilute to 50 ml and pipette three 5.0 ml portions into 10 ml beakers. Evaporate these portions to dryness.

IV. DETERMINATION OF THE METALS

A. Method for Copper, Cadmium, Nickel, and Zinc.

(1) Reagents:

a. Electrolyte-1M with respect to NH_4Cl and NH_4OH; 0.2 ml Triton X (10%) per liter.

b. Nitrogen gas.

(2) Procedure:

a. Add 5.0 ml of the electrolyte to the dried aliquot (10 ml beaker) and allow to stand at least 5 minutes.

b. Police sides and bottom of beaker and transfer to cell.

c. Bubble nitrogen through sample 5 minutes, then add mercury pool.

d. Record polarogram.

e. Advised settings: Sensitivity .002 (if Range Extender available, otherwise use .003), Voltage range 0 to -2.

B. Method for Chromium.

This method, based on the conventional procedure for oxidation of chromium, was developed by the GLIRBP laboratories.

(1) Reagents:

a. H_2SO_4 (0.5N)
b. $KMnO_4$ (.1%)
c. NaN_3 (1%)
d. NaOH (2N); 0.5 ml Triton - X (10%) per liter.

(2) Procedure

a. To the dried aliquot (in 10 ml beaker) add 2 ml H_2SO_4 (.5N) + .1 ml $KMnO_4$ (.1%) and heat just below boiling 5 min. (Add more $KMnO_4$ if red color fades)

b. Add 2 drops NaN_3 (1%) and continue heating until colorless; add more NaN_3 if not discolored in 30 seconds.

c. Remove from heat and add 1.0 ml 2N NaOH + Triton - X within 10 min. and make up to 5 ml with double-distilled water.

d. De-aerate 5 minutes with nitrogen and add mercury pool.

e. Record polarogram.

f. Advised settings: Sensitivity .002, voltage range 0 -- -2.

V. STANDARDS

1. A stock standard solution was made by dissolving the salts of the metals in water or the metals in nitric acid and mixing them in definite proportions. The mixed standard then contained 0.005 mg of each metal per 0.5 ml.

2. A working standard was prepared by diluting 100 ml of stock standard to 1 liter. This working standard contains .005 mg of each metal per 5.0 ml.

3. A 5 ml portion of this working standard was pipetted into a 10 ml beaker and evaporated to dryness. This standard was treated exactly as the samples and the comparative wave heights were used in calculating the amount of the metals in the samples.

VI. HALF-WAVE POTENTIALS WITH MERCURY POOL ($E\frac{1}{2}$)

Metal	Electrolyte	$E\frac{1}{2}$
Cu)	1M NH_4OH + 1M NH_4Cl	-.32 -- -.36
Cd)		-.62 -- -.67
Ni)		-.90 -- -.95
Zn)		-1.16 -- -1.22
Cr	NaOH	-.68 -- -.73

VII. CALCULATIONS

The following formula contains all the necessary factors for calculating the amounts of metals:

$$\text{mg/l} = \lambda H \text{ Sample} \times \frac{\text{mg in 5 ml std}}{\lambda H \text{ std}} \times \left[\frac{\text{Final Volume of concentrate}}{\text{Volume of concentrate taken}} \times \frac{\text{S. of sample}}{\text{S. of std}} \times \frac{1000}{\text{sample volume taken}} \right]$$

where mg/l = milligrams per liter of metal in sample
λH = wave height
S = sensitivity
Std = standard

Analytical Results

The analytical results presented in the subsequent sections are the arithmetic averages of the individual results collected during the study period. These data conform with the sampling periods listed in Chapter IV except for certain data collected during the March-April study of the lower river. Some of the data collected during this period was separated into a March and April grouping to show the possible effects of spring runoff which occurred at that time. These will be apparent in the subsequent discussions of the analytical results obtained in this study.

Temperature

The temperature of water is usually the result of natural phenomena. However, multiple usage by man has often resulted in significant changes in the normal temperature ranges of a stream and has upset the life cycles of the aquatic biota. Temperature controls the concentration of oxygen which can be dissolved in water. This is an inverse relationship in that less oxygen can dissolve as the temperature rises. For example, at sea level barometric pressure (760 mm. mercury), the saturation value is 14.6 milligrams per liter at 0° C and 7.6 milligrams per liter at 30° C. (1) Temperature also affects the rate of oxygen utilization by organic matter; the rate increasing with rising temperature. Thus, high water temperatures affect dissolved oxygen in two ways: they lower the saturation value and speed the consumption of oxygen. Unnaturally high temperatures may cause fish deaths, and disrupt normal biological activities. The efficiency of water for industrial cooling processes, including steam power generation, decreases as temperature increases.

Figures V-1 and V-2 present the average values of water temperature taken at the time of sample collection for each of the stations during the sampling periods designated. Figure V-1 describes the observed temperature of the Upper Illinois water system. A rise in temperature is displayed as the water passes through the waterway system. Higher temperatures are displayed below points of treatment plant and cooling water discharge, resulting in a net rise in temperature of about 9°C for the upper waterway. The significance of this net rise on other factors affecting the water quality of the waterway can be illustrated by considering the July averages. Incoming water, at 18°C can hold a maximum of 9.5 mg/l dissolved oxygen. The 9° temperature rise would reduce this value to 8.1 mg/l, thus accounting for a net loss of 1.4 mg/l oxygen on the basis of temperature alone, excluding all other factors. To this is added the increase in rate of oxygen consumption by decomposing organic matter, in the natural purification processes. A net temperature rise of 9° increases this rate to 1.6 times the initial rate. This temperature influence on oxygen consumption creates a greater likelihood of nuisance conditions.

Temperature averages for the Grand Calumet-Little Calumet system represent only a single monthly period. The Grand Calumet data indicates abnormally high temperature values, which may be the result of numerous industrial and cooling discharges into this small stream.

Temperature averages of the lower river, as presented in Figure V-2, appear to follow seasonal patterns with little or no evidence of unusual, local increases. This is to be expected because the volume of water available for dilution in the lower river would minimize effects by all but major inputs of heat. Of the four study periods represented on this Figure, the March study had the lowest temperature-varying between three and four Centigrade degrees. The November study period showed variations between six and ten Centigrade degrees, with a trend to lower temperatures at the downstream points. April temperature variations at most stations were between seven and eight Centigrade degrees but extreme ranges of six to nine degrees have been observed in some cases. The July averages ranged between 24 and 27° Centigrade; the warmer waters occurred at the Kankakee confluence and again in the lower reaches of the stream.

Hydrogen Ion Concentration (pH)

The data in Figures V-3 and V-4 are averages of pH observations, taken daily, during the study periods reported. Averages are presented because there was little variation in observed day to day pH values.

pH is defined as "the logarithm of the reciprocal of the hydrogen ion concentration or, more precisely, of the hydrogen ion activity - in moles per liter(1). pH 7 is the neutral point, or dividing line between an "acid" and an "alkali"; pH values below 7 indicate an acid condition, values above 7 indicate an alkaline condition. Each unit change in pH indicates a tenfold change in hydrogen ion concentration; e.g., pH 6 is 10 times stronger than pH 7, and pH 5 is 100 times stronger than pH 7.

The pH value of water is significant for several reasons. Low pH values (acidity) disrupt biological activity, cause corrosion of steel and concrete, intensify the effect of toxic materials such as sulfide and cyanide, interfere with water plant coagulation practices and tend to add undesirable iron and manganese to the water. High pH values (alkalinity) also disrupt biological activity, precipitate calcium and magnesium from water and increase the toxicity of ammonia and other amines.

Figure V-3 presents the range of pH values encountered in the Upper Illinois River system and tributaries for the periods of study indicated. Shortly after the high pH waters (pH 8.5) enter the main channel a sharp drop occurs due to mixing with the lower pH water of the Northside Treatment Plant effluent. This lower pH condition (pH 7.4-7.7) persists throughout the main channel as far as the Kankakee confluence where a rise to pH 8.0 occurs. The Cal Sag Channel shows a similar pattern in its confluence with the main channel, with perhaps a slightly greater range of pH change (pH 7.0-7.7), in the general vicinity of the Calumet Treatment Plant discharge. The Grand Calumet tributary, in the single period of study, showed a lower pH (7.1-7.3) than did the other streams; this difference may be attributed to discharges from numerous industrial outlets to that stream. No important pH changes are apparent from the inspection of these data; the overall pH range is within the neutral to slightly alkaline zone of the pH scale. Conclusion: no adverse pH conditions existed in the upper Illinois River system during this study period-except for possible localized situations which may have occurred between sampling points but which were insufficient to influence significantly the entire stream.

The averages of the pH values encountered in the four periods of study of the Lower Illinois River are presented in Figure V-4. These averages, varying between pH 8.2 and 7.2, indicate no adverse pH conditions in the lower river during this period of study. It is concluded that pH is not a critical factor, at this time, in the water quality of the Illinois River.

Dissolved Oxygen (DO)

Gaseous oxygen dissolved in water is one of the most important constituents of a natural water. The existence of desirable aquatic life is dependent on the presence of adequate levels of oxygen at all times. Because the solubility of oxygen in water is low, and is adversely affected by both physical and biochemical forces, the maintenance of satisfactory levels is a delicate balance between the forces utilizing oxygen and those contributing it.

Oxygen is consumed by aquatic organisms during the processes of respiration. It is replenished from the atmosphere by physical forces and can also be added through photosynthesis by aquatic plants and algae. When organic pollution enters an aquatic environment, the balance between consumption and contribution is upset. The bacteria present in water or introduced with the pollution begin active consumption of the organic matter, multiplying rapidly in the process, and consume the oxygen present in the water. If they consume oxygen at a rate greater than the rate of atmospheric reaeration, the imbalance created in the stream results in an oxygen deficiency which, if great enough, can cause the death of fish and other desirable aquatic life and can convert the stream into an odoriferous nuisance. In polluted streams, these conditions are particularly in evidence during warm weather when rate of oxygen consumption is increased, the ability of water to hold oxygen in solution is decreased, and the natural flow of streams is at a minimum providing a minimum availability of dilution water in proportion to the waste applied.

Upper River:

The sampling points of the Upper Illinois River system were analyzed for dissolved oxygen throughout this study period. The data presented in Figures V-5, 6 and 7 represent the average values observed. In the main channel of the upper river system the DO entering at the Wilmette inlet was at or above saturation throughout the study period. As the water progressed downstream, DO was observed at all stations to the junction of the inlet waters of the Chicago River. The extent of the depletion was least during the cold months and greatest during the warmer seasons-when it approached zero at a station above the confluence of the North Branch with the Chicago River. Beyond the confluence, a sharp DO rise, caused by lake water entering the system, was observed; thereafter the DO contents continued to decline. In the reach between the Chicago River inlet and the Calumet Sag Channel the DO dropped from about six mg/l to two mg/l in April, May and June and from four mg/l to less than one mg/l in July and August. The January drop was from ten to five mg/l. Between the Calumet Sag confluence and the Lockport Dam, there was little or no oxygen remaining during the summer months.

Water at the Calumet Sag Channel inlet was lower in DO than at the other inlets, although much higher than at other downstream points. This may be caused by the periodic reversals of flow occurring in this portion of the Channel. Downstream points on the Calumet Sag showed progressive DO depletions. The lowest DO (less than one mg/l) was observed during the summer sampling period at points above the junction with the Sanitary and Ship Canal.

The Grand Calumet and Little Calumet rivers-both tributary to the Calumet Sag Channel-showed significant oxygen depletion in the one month (February) when these streams were studied. The greatest depletion occurred on the Grand Calumet, where DO dropped as low as four mg/l at two points. It should also be pointed out that the DO content of the Grand Calumet, at its confluence with the Calumet Sag Channel, was consistently below that of the channel. Zero or near zero DO levels were observed during most of the study period.

At Lockport water flow of the Upper Illinois River system passed through navigation locks and through the hydraulic power plant where aeration occurred. This raised the DO content from near zero to about seven mg/l during the critical summer period. Between Lockport and the Kankakee confluence, further depletion was observed. The DO dropped to about four mg/l. The mixing of high DO waters of the Kankakee River, and further aeration on passage over the Dresden Dam, restored the DO of the river to near saturation at the point marking the beginning of the Lower Illinois River.

Lower River:

The DO profiles for the Lower Illinois River are presented in Figure V-8. This figure represents the average DO observed at various sampling points on the main stem and tributary mouths for the periods indicated. During the cooler seasons of this study (i.e. namely November 1961, March and April 1962) the average DO was at or near saturation-well above critical levels for aquatic life. Minor drops in DO content in the stream reaches between dams were insufficient to be of concern from a water quality standpoint.

However, the summer study period revealed an entirely different picture. Because there were lower flows and higher water temperatures during this period, two important zones of oxygen depletion were observable: one was in the stretch between mile points 230 and 184, the other was between mile points 157 and 81. In the first stretch, oxygen levels dropped from 7.7 mg/l to 4.2 mg/l; in the second stretch, DO dropped from 6.0 mg/l to 2.6 mg/l. These low dissolved oxygen levels were significantly below those levels required to support desirable fish and aquatic life in streams. (2)

Biochemical Oxygen Demand (BOD)

The introduction of organic waste into water - whether the waste originates from domestic sewage, industrial processes, land runoff, or any other source - initiates a chain of events involving the organic material, microorganisms accompanying it, and the natural biota present in the receiving water. Organic matter is rapidly utilized as food by those organisms capable of converting it; the net result of this action is consumption of dissolved oxygen. Because control of dissolved oxygen is important in water quality management programs, a means of measuring the oxygen depletion potential of wastes is necessary if adequate control measures are to be adopted. The test commonly used for this purpose is the BOD test.

The BOD test is based more on bioassay than a well defined chemical reaction; it involves observation of oxygen usage by microorganisms which convert unstable organic matter into cellular material; and respiratory products. Waste material is utilized as energy to effect this conversion. Toxic substances, if present, adversely influence this test.

The routine test involves measurement of dissolved oxygen initially present in a sample, and of DO remaining after incubation of the sample, in the dark, for a stated time interval (generally five days at 20° C.). Special determinations made at frequent intervals over an extended period of time are necessary to measure the rate at which oxygen demand is exerted.

Oxygen demand of the waste, and the physical, chemical and biological characteristics of the receiving waters must be correlated in order to evaluate stream conditions and to design waste treatment facilities.

In general, high BOD values can be expected to result in low dissolved oxygen levels in the receiving waters; this implies a less than optimum environment to fish and other desirable aquatic life, greater need for chlorine and chemicals for water treatment, and a deterioration of the quality of treated water because undestroyed organic residues are present.

The Upper River:

Figures V-9, 10 and 11 present five day BOD averages of the river stations for the sampling periods indicated. The BOD of representative samples of Lake Michigan waters was very low (about one mg/l or less); waters entering the river system at various inlets showed higher values throughout most of the study period. This was investigated for the Wilmette inlet waters and is discussed in Chapter VIII.

During the April-May period, the BOD of incoming water at Wilmette averaged 5.5 mg/l. This level did not change appreciably until mile point NS 334.9; there a sharp rise, to 9.0 mg/l, demonstrated the influence of the Northside sewage treatment plant discharge. Beyond this point the BOD varied between 8.5 and 5.5 - gradually diminishing to the lower value until a sharp rise to 11.0 ppm occurred at mile point SS 314. The rise was caused by the West-Southwest sewage treatment plant discharge. From this point on, the BOD declined to a value of 4.5 at the IR 271.5 mile point; a minor rise at mile point 285.8 was caused by discharges from the Joliet area.

The Cal Sag averages showed an initial BOD of 4.0 mg/l gradually rising to a high of 8.5 at mile point 320.2 (because of the Calumet treatment plant discharge) and slowly diminishing to 6.0 at its confluence with the Sanitary and Ship Canal.

The June and July averages followed the same pattern exhibited by the April-May period except that the BOD continued to rise between mile points NS 334.9 and NB 325.8. The incoming BOD at Wilmette was 4.0-4.5; it rose to a peak of 10.5-11.0 at the first station below the West-Southwest treatment plant and then diminished to 4.5-6.0 at mile point IR 271.5.

The BOD pattern during June in the Cal Sag Channel followed closely the April-May pattern. The incoming BOD of 3.5 rose to a peak of 11.0 at mile point 320.2, then diminished gradually to 6.5 at the confluence of the Sanitary and Ship Canal. During July the incoming BOD of 2.5 rose to 12.5 and diminished to 5.0.

The pattern resulting from the August averages - although similar to the earlier patterns - showed an overall lower BOD. Incoming BOD at Wilmette was only 3.0; this rose to a maximum of 7.0 below the West-Southwest treatment plant, then dropped very slightly over the remainder of the waterway, ending with an average value of 5.0.

The Cal Sag Channel for this period of observation demonstrated a similar pattern, exhibiting lower values throughout its course.

The January study results presented a pattern somewhat different from the other studies. Here discharges from the Northside, Calumet, and Stickney treatment plants stood out sharply. The BOD of the Grand Calumet Tributary to the Calumet Sag was considerably higher than that of the main channel - ranging between 10 and 30 mg/l throughout its course. The Little Calumet River averaged between five and ten mg/l during this winter study period.

If the sources of BOD entering the river system were limited to effluents discharged from the three treatment plants, a gradual reduction in BOD between the point of entry of one effluent to the point of entry of the next effluent would be expected. Examination of the data reveals numerous increases in BOD at intermediate points; this suggests the entry of other waste discharges throughout the river course.

The Lower River:

Four periods of study are presented in Figure V-12 showing the averages of the observed BODs for the Lower Illinois River. Inventory data presented in Chapter III show comparatively little additional BOD entering this stretch of the stream, except in the Peoria area (mile points 166-142). On the other hand, there are significant increases in measured BOD in the upper half of the lower Illinois River from its beginning at mile point 273 down to about mile point 210; this is followed by a BOD reduction to mile 170, then an increase again to mile point 125 and a gradual reduction below this point to the terminal stations of the study. Because this high BOD cannot be accounted for (except in the Peoria area) in terms of introduction of fresh wastes entering the stream, other causes for this high oxygen demand must be explored. One very apparent cause is the high ammonia nitrogen concentration, available for oxidation by microorganisms, in the Upper Illinois River system. It is well known that the BOD reaction consists of two separate events - the oxidation of carbonaceous material followed by oxidation of nitrogenous matter. Although the two can occur simultaneously, most studies reveal two separate events. This data, when compared with corresponding data on changes in ammonia nitrogen concentrations, shown in Figure V-27, clearly indicates this relationship.

In every one of the periods studied, the rise in BOD was paralleled by a corresponding drop in ammonia nitrogen.

The effect of this high BOD on the dissolved oxygen is evident from the July '62 data on DO presented in Figure V-8. Here the data revealed a steady fall in DO from about eight mg/l to almost four mg/l between mile points 230 and 184. Because the control of dissolved oxygen, at levels high enough to support desirable aquatic life, is an important objective of water quality management, these data should serve to point out that the removal of carbonaceous BOD by sewage treatment plants will not by itself satisfy the objective to be met - if the lower Illinois River is to support desirable fish and aquatic life.

A significant rise in BOD was observed between mile points 166 and 125. This rise corresponded to a significant drop in DO from 6 mg/l to 2.5 mg/l, between mile 166 and mile 88 during the summer study. BOD discharges in the Peoria area are believed to be the primary cause of the observed DO drop.

The BOD test, as an important criterion of water quality, reveals the potential oxygen depletion that can be expected under conditions favorable for natural processes of stream purification. To maintain a satisfactory DO level, control must be exercised over the quantity of oxygen demanding wastes permitted to enter a stream. Lack of control can lead to oxygen depletion below the critical levels that can be tolerated for other beneficial stream uses; this results in a general degradation of water quality and creates nuisance conditions, and taste and odor problems.

The data presented in this section clearly shows that the three Metropolitan Sanitary District plants are major sources of BOD entering the stream; their influence is extended throughout the entire Illinois River system. Other major BOD sources are the numerous storm water outlets and other outfalls in the Upper River system and in the Peoria area in the lower river. Quantitative data will be presented in Chapter IX to show the extent of the BOD loadings observed.

Chemical Oxygen Demand (COD)

The COD test provides information concerning the total oxidizable organic load present. COD tests, used in conjunction with the BOD test, enable judging whether a sample contains contaminants which are resistant to biological action, detecting the presence of toxicity which may inhibit bacterial decomposition of waste organic matter, and observing the relative stability of the organic matter present (i.e. is the organic matter fresh in origin or has it already undergone stabilization through treatment?). If both COD and BOD are low, the water under test is considered to be relatively free from oxidizable organic matter -- a condition normally existing in unpolluted streams. A low BOD coupled with a high COD may indicate stabilized organic matter, organic matter not subject to biological degradation, or the presence of toxic substances which inhibit biological activity. A high BOD coupled with a high COD would indicate heavy organic contamination. In this instance a COD/BOD ratio much higher than 2/1 would reveal organic matter present which is not being discovered by the BOD test. Normal domestic sewage should have a COD/BOD ratio between 1.5/1 and 2.0/1.

The COD values observed in the upper Illinois River system for the January '62 study period are presented in Figure V-13. These values range from a high of 50 mg/l, immediately below the treatment plants, to a low of about 11 mg/l for the inlet waters entering the river system from the lake. In general, the COD pattern was observed to follow the BOD pattern in Figure V-11. It is also apparent that the COD value was four to six times greater than the corresponding BOD value; this indicated the presence of organic matter not readily available as BOD.

The averages of COD values observed for the lower Illinois River for the periods of study indicated are presented in Figure V-14. In general, these values parallel the BOD averages for the same periods. Outstanding deviations, noted for stations downstream from Peoria (during the November study), reflect higher flows encountered for this stretch of stream. This can be attributed to the higher silt load carried. The March study shows a similar rise in COD in the upper portion of the lower river, reflecting the high flows encountered there. The July data for COD were similar to the BOD data for that period, except for the lower ratios observed. This may be attributed to the high nitrogen BOD experienced during this period, which is not measured by the COD test. COD values encountered in the lower river ranged from 23 mg/l to 53 mg/l, indicating the presence of residual carbonaceous matter not readily oxidizable by biochemical processes.

Suspended and Dissolved Solids

Suspended solids tests measure the amount of material suspended in the stream that can be filtered out by standard filtration methods. The materials in suspension, upon settling, cause sludge or silt concentrations which alter the biological habitats of aquatic life and sometimes interfere with navigation. Sludge banks resulting from putrescible organic matter are unsightly, odoriferous nuisances and contribute to the oxygen demand of the stream passing over them as a result of the anaerobic digestion products released by the sludge.

Dissolved solids tests measure the total amount of soluble material carried by the stream. This includes both organic and inorganic matter. Excessive dissolved solids in water can be unpalatable, and increase the cost of water treatment for many water uses. The Drinking Water Standards of the U.S. Public Health Service recommend the rejection of sources providing water containing over 500 mg/l of dissolved solids(if another water source is available) because of a noticeable saline taste, and possible cathartic effect on many individuals.

The Upper Illinois River system was studied only during January of 1962. Because an insufficient number of analyses were performed during this sampling period, the available data are not considered representative and have not been included in this report.

The data collected on the Lower Illinois River are presented in Figures V-15 and 16.

Suspended Solids:

The suspended solids results for the lower river are presented in Figure V-15 for three study periods. Except for minor fluctuations between mile points 270 to 143 attributable to tributary inflow followed by settling, no significant variations were apparent. The levels fluctuated between 30 mg/l and 120 mg/l. Below mile point 143, sizeable inputs of suspended solids were observed during November and July, rising as high as 420 mg/l in November and 190 mg/l in July. The November input can be explained by the large flow contributions from the tributary streams (particularly the Sangamon and the Spoon Rivers) and runoff resulting from local rains. (See Figure V-32). The July increase was unexplainable at that time.

Dissolved Solids:

Figure V-16 presents the average of the dissolved solids concentrations found in the lower river during the three study periods. The March period exhibits the lowest average concentrations throughout the river, ranging between 220 mg/l and 370 mg/l, and reflecting the effect of the higher flows encountered at that time.

In July the average concentrations observed varied between 340 mg/l and 375 mg/l.

The November 1961 averages varied between 400 mg/l and 510 mg/l.

Chloride

This is a component of the dissolved ionized solids present in most surface waters. It is closely associated with man's activities since it is a component of urine and is also used freely in many industrial processes. Chloride can produce a salty taste to drinking water and render it unpalatable. Many waters are unsuitable for domestic use, irrigation and industrial processes because of high chloride content. The Drinking Water Standards of the U.S. Public Health Service recommend the rejection of sources providing water containing over 250 mg/l chloride if other water of better quality is available. It is not treatable by conventional water and waste treatment methods. Increased chloride concentration would imply deterioration in water quality for many beneficial uses.

The upper Illinois river system was studied only during January of 1962. The results of this study are presented as average values for the various stations in Figure V-18. The waters of Lake Michigan entering the inlets of the Upper Illinois River system contained about 7.0 mg/l of chloride. This concentration increased rapidly (because waste discharges from the treatment works and other sources entered the river system) and reached levels as high as 140 mg/l in sections of the upper river. Following dilution from various sources, the chloride content below the junction of the Kankakee was reduced to about 50 mg/l. The major sources of chloride were the treatment plant effluents, as expected; but when a comparison was made with the normal chloride concentration of these effluents (58 mg/l as reported in Chapter VIII), the effect of the wintertime practice of salting city streets for ice removal became apparent.

Average chloride concentrations found in the Lower Illinois River during the study periods indicated are reported in Figure V-19. This figure presents the averages of observed values obtained during the four indicated study periods. The March and April periods reflect the dilution effects of high flows which occurred during these periods of study. They ranged between 11.0 mg/l and 25.0 mg/l. In the November period, chloride ranged between 20.0 mg/l and 37.0 mg/l; in July between 22.0 mg/l and 33.0 mg/l. These levels, all well below the permissible levels set forth above, would not be considered detrimental to water quality related to beneficial uses of the Illinois River.

Alkyl Benzene Sulfonate (ABS)

This test is a measure of the large, anionic-type molecules which, in streams, are representative of the synthetic organic detergents now contaminating many surface and ground waters. The ABS is that portion of a common household or industrial cleaning compound that imparts foam and reduces surface tension to aid in the removal of dirt particles by the cleaning compound. ABS compounds are new to the water environment. They have been used as substitutes for soap only in recent years. They pass through water and sewage treatment processes with only partial reduction in concentration; moreover, they are not readily attacked by stream purification processes. Consequently, ABS can be found for many miles below sources of waste water discharge. ABS is believed to be nontoxic to man (3) (4) in the concentrations found in contaminated waters; but it produces unsightly, persistent foams in streams at points of agitation or discharge over dams. The ABS content of drinking water is limited to 0.5 mg/l by the U.S. Public Health Service Drinking Water Standards.

The ABS data obtained in the upper Illinois River system are reported as averages for the January study period, in Figure V-20. Except for waters entering inlets to the upper Illinois River system, waters from nearly every station sampled revealed ABS above the limits of 0.5 mg/l described above. Values as high as 2.0 mg/l were found below the principal treatment plant discharges.

ABS data collected on the lower Illinois River are presented in Figure V-21. This data represents averages of samples collected during the study periods indicated. The range of values observed during the November period was between 0.42 and 0.14 mg/l; the higher values were observed in the upper reaches of the stream. In March, the values ranged between 0.14 and 0.30; in April between 0.19 and 0.56; and in July, between 0.28 and 0.76. It is evident from these data that in a large portion of the lower Illinois River the ABS values are above the limits of the Drinking Water Standards, particularly during the summer season when low river flows prevail.

Total Phosphate

Phosphate is a necessary nutrient for biological activity. Its presence in the water will permit the processes of stream purification to proceed at an optimum rate. Also, its presence in water is not considered harmful to human health. Excessive concentrations of phosphate - coupled with other favorable conditions such as abundant nitrogen supply, optimum temperature and sunlight - can result in massive growths of algae and plankton. These excessive growths affect the quality of water downstream, interfere with water treatment operations, increase taste and odor problems, cause unsightly scums and decaying matter, and create problems of dissolved oxygen control. Concentrations of phosphates between 0.03 and 0.3 mg/l are needed to stimulate algae growth according to various authors. Sawyer (5) states that "nuisance conditions can be expected when the concentration of inorganic phosphorus exceeds or equals 0.01 ppm." The biological impact of phosphate is discussed further in Chapter VI, Biological Investigations.

Phosphate enters the stream with sewage treatment effluent because it is removed only with solids in conventional processes. It is normally present in human and animal waste products; synthetic detergent formulations used in modern day washing practices have further increased the quantities discharged to the stream. Phosphate is also present in surface runoff, particularly from fertilized fields, and may be a component of the effluent from industrial processes.

The average phosphate concentration of the Upper Illinois River system for the January study period is presented in Figure V-22. As the incoming lake waters mixed with effluents discharged by the treatment works the phosphate level rose at one point from less than 0.1 mg/l to over 10.0 mg/l. Following dilution by additional lake water, the phosphate level of the upper river dropped to a three to four mg/l range and remained near this concentration to Lockport. A rise to six mg/l was observed between Lockport and the Kankakee confluence.

The Calumet Sag channel revealed a similar pattern of phosphate concentration change; it was due to the large addition from the Calumet treatment works. The Grand Calumet and Little Calumet tributaries also showed high phosphate values, as would be expected of streams receiving domestic and industrial wastes.

In the main channel of the upper Illinois River system, between Lockport and the Kankakee river, the observed rise of 3.0 mg/l in phosphate concentration was unexpected. The volume of domestic waste contribution, in relation to the larger stream flow in this stretch, would not be expected to result in such a large increase. Quantitative calculations (presented in Figure V-23) revealed a sizeable contribution, equivalent in quantity to the total contribution of the effluents from the Chicago area. The only known source of phosphate, other than domestic wastes in this stretch of stream, is from a chemical manufacturing plant located at Joliet. Water Quality management programs concerned with the lower Illinois River cannot overlook this source of phosphate if control of plankton and algae nuisances is to be exercised.

Phosphate averages obtained from studies of the lower Illinois River and tributaries are presented in Figure V-24. These results show the influence of stream flow on the results obtained; the March and April data, representing high springtime flows, revealed much lower concentrations at all sampling points. The July and November data show a steady drop in phosphate levels - from 2.5 mg/l to 0.3 mg/l as the water moves downstream. Because phosphate results were obtained from samples from which suspended matter had been filtered, the observed decrease in phosphate concentration can be attributed to its removal by the plankton and algae present in the stream, and to dilution effects of water from tributaries and backwater lakes of the lower river.

Organic, Ammonia and Nitrate Nitrogen

The presence of nitrogen compounds in the stream (except for high nitrate concentrations or specific nitrogen compounds such as cyanides or amines) is not considered significant to health. Nitrogen, like phosphorus, is necessary to the normal life cycle of aquatic life; if it is present with phosphorus in optimal concentrations massive growths of algae and plankton can result under otherwise favorable conditions. Ammonia is a substance toxic to many forms of aquatic life (at high levels and under alkaline pH conditions (2)). Amines and cyanides have toxicity properties peculiar to specific compounds containing these chemical groupings. Nitrate nitrogen (2) has been implicated as the cause of Methemoglobinemia in infants; a limit of 45 mg/l of nitrate has been included in the Drinking Water Standards of the U. S. Public Health Service.

In the stream, nitrogen compounds present in one form are readily converted into other forms by various biological changes. The nitrogen cycle has been a phenomenon much studied by biologists and biochemists interested in the role of nitrogen in biochemical processes. Complex reactions result in a never ending cycle as life processes transform nitrogen gas to nitrogen oxides, to ammonia, protein and back to nitrogen gas.

Of particular concern, in terms of water quality, are the changes that occur in streams receiving waste discharges. In the waste treatment plant, microorganisms convert some of the nitrogen, received as ammonia and urea from human wastes to protein, which is then settled out as sludge. Another portion may be converted to nitrite and nitrate. The effluent may contain varying amounts of nitrite, nitrate, ammonia and organically bound nitrogen. The effect of these materials upon the receiving stream is complicated by the condition of the stream receiving the effluent. Streams already depleted in DO will utilize oxygen in nitrate, thereby converting the nitrate to ammonia, nitrogen gas and proteinaceous matter. Streams with sufficient oxygen resources will continue the oxidation or assimilation of ammonia to proteinaceous material, nitrogen gas, nitrite and nitrate. As discussed in the section under BOD, oxidizeable nitrogen becomes a part of the biochemical oxygen demand exerted on the stream.

The Upper Illinois River System:

Organic and ammonia nitrogen determinations were carried out during the January study of the upper river. Averages of the observed values are presented in Figure V-25. As the incoming lake waters mixed with effluents discharged by the treatment works, the organic and ammonia nitrogen concentrations rose rapidly. Values of organic nitrogen as high as two mg/l were observed below treatment plants; ammonia nitrogen values rose as high as seven mg/l at one point. Respective concentrations of 1.5 mg/l and 4.0 mg/l were found at the station immediately upstream from the Kankakee confluence.

The Lower Illinois River System:

Organic, ammonia, and combined nitrite-nitrate nitrogen determinations were carried out during four periods of study. These data are presented as Figures V-26, 27 and 28.

Figure V-26 presents the averages of the values observed for organic nitrogen during the periods of study indicated. Wide fluctuations (between 1.0 and 2.0 mg/l) were observed as the water moved downstream. These fluctuations are believed to result from changes in the nature and quantity of aquatic life at succeeding sampling points; they therefore reflect the quantity of proteinaceous material present. Since proteinaceous nitrogen is one phase of the complex nitrogen cycle, the observed levels serve to point out that a reservoir of stabilized organic matter was present throughout the study periods.

Figure V-27 presents averages of the values observed for ammonia nitrogen for the same study periods. Data for the November '61 study period revealed diminishing concentrations of ammonia nitrogen as the water moved downstream; the concentration dropped from 1.0 mg/l at the Kankakee confluence to 0.26 mg/l at mile point 78 - the terminus of this study. This reduction can result from bio-oxidation to nitrate as well as dilution by tributaries and inflows from the backwater lakes.

The data for March revealed little change in ammonia nitrogen concentration as the water moved downstream, probably because the colder temperatures during this period reduced the oxidation rate of ammonia. The observed concentration (1.0 mg/l at the Kankakee confluence) dropped to 0.75 mg/l at one point, then rose again to the 1.0 mg/l level for most of the stream reach studied.

The data for April was comparable to the November results; it followed the same general pattern, but at slightly higher levels.

The most striking changes are represented by the results of the July study. Beginning with a concentration level of 3.0 mg/l at the Kankakee junction, a rapid reduction (to 1.2 mg/l) was observed to occur between that point and mile 209. This level remained constant to mile 184 then dropped sharply to 0.75 mg/l at mile 166. A slight rise was observed at stations enveloping the Peoria section of the stream, followed by further reductions at downstream points to a level of 0.25 at mile 21 near the mouth of the Illinois River. Comparison of these data with that of the dissolved oxygen values in Figure V-8 show similar zones of oxygen depletion which parallel the losses of ammonia nitrogen. The combination of warm water temperature and low flow coupled with high initial concentrations of ammonia nitrogen - as observed in the July study period - revealed the oxygen-demanding potential of this water quality parameter; it should be an important consideration in a water quality management program for the Illinois River.

In Figure V-28 are presented the averages of the nitrite plus nitrate values observed during the periods of study indicated. The November study revealed a fairly constant level of oxidized nitrogen; it fluctuated between 2.0 and 2.5 mg/l at most stations. The March data revealed a similar pattern; fluctuations were between 1.5 and 2.0 mg/l. In the April period, the oxidized nitrogen level rose from about 2.0 to over 3.0 mg/l between the Kankakee mouth and mile point 184 and fluctuated between 3.0 and 3.5 at the succeeding downstream stations. The July study followed a similar pattern beginning at a level of 0.75 mg/l and reaching a peak of 2.1 mg/l.

The significance of these oxidized nitrogen levels - in addition to their nutrient properties discussed earlier - is an indication of a potential danger that can exist when these waters are used in infant feeding formulas. A nitrate nitrogen value of 3.5 mg/l is equivalent to 15.5 mg/l nitrate. Although this level is below the 45 mg/l limit of the Drinking Water Standards, further increases in nitrogenous matter discharged to the Illinois River can result in levels of nitrate approaching the limits of safety. This is further justification for control of nitrogen discharges to the Illinois River.

Toxic Metals

The U.S. Public Health Service Drinking Water Standards limit the concentration of certain metals in drinking water because of potential toxic properties to humans. These limits are as follows: Arsenic, 0.05 mg/l; Barium, 1.0 mg/l; Cadmium, 0.01 mg/l; Chromium, 0.05 mg/l; Lead, 0.05 mg/l; Selenium, 0.01 mg/l; and Silver, 0.05 mg/l. The presence of any of these elements in excess of the concentration listed shall constitute grounds for the rejection of the water supply. In addition, the Standards list tolerance limits for metals that, if exceeded, can constitute grounds for rejection if other suitable supplies can be made available. These are as follows: Arsenic, 0.01 mg/l; Copper, 1.0 mg/l; Iron, 0.3 mg/l; Manganese, 0.05 mg/l; Zinc, 5.0 mg/l. The basis for rejection in this tolerance list is not toxicity in all cases but is also related to consumer acceptance. In addition to human toxicity, some of these metals are toxic to aquatic life and can play an important part in the biological makeup of the aquatic environment.

In the studies of the Upper and Lower Illinois River system, five metals, considered as having toxic properties in relation to beneficial water uses, were studied in detail. These were Copper, Cadmium, Chromium, Nickel and Zinc.

Copper occurs in natural waters only in trace amounts. Excessive quantities are generally the result of pollution, attributable to the corrosive action of water on brass or copper piping, to industrial wastes, or to the use of copper for the control of undesirable plankton organisms. Copper in water may be detrimental for some industrial uses and has been found toxic to a wide variety of aquatic organisms, including bacteria and fish (2).

Cadmium is one of the least abundant metals present in the earth's crust and is rarely found in natural waters. It is invariably present in zinc to some extent. Its uses are limited principally to industrial applications, therefore quantities found in water are the result of industrial pollution. It has been found to be toxic to man when ingested, therefore its presence in water is a definite health hazard. It is also toxic to aquatic life, including fish (2).

Trace concentrations of chromium are found in some natural waters but excessive concentrations arise from its industrial uses. It is extensively used in electroplating, tanning, paints, and many other industries, and is used to control corrosion in cooling water systems of power plants. Its toxicity to humans when ingested in water is subject to some question, but because of its pronounced toxicity and carcinogenic properties when present in other paths of exposure, the limits set for drinking water reflect these considerations as a factor of safety. Its toxicity to aquatic life covers a broad range, being toxic to some of the smaller organisms at levels as low as 0.05 mg/l (2).

Nickel is not a common constituent of natural waters, its presence being related to industrial waste discharges. Its toxicity to humans is low and is not considered important. It is toxic to aquatic life but less than copper or zinc (2).

The principal effect of zinc in drinking water is aesthetic; it imparts a noticeable metallic taste to water above 5.0 mg/l. However, it has a marked toxic effect on fish and aquatic life; its toxicity is noticeable at concentration levels of 0.1 mg/l in soft waters (2). In nature, zinc can be present in waters draining mining areas but its most frequent source is from waste effluents from many industries. Galvanized piping may contribute zinc to drinking water.

Figures V-29 and 30 present the results of samples collected in the Upper Illinois River system during the January study period. The values represent a single analysis of a composite of the samples collected during this period. Zinc was found at all stations of the main channel, varying between 0.35 and 0.10 mg/l. The Calumet Sag Channel results showed concentrations varying between 0.44 and 0.15 mg/l. The highest concentration, 1.1 mg/l, was found in the Grand Calumet tributary.

Chromium was observed up to about 0.05 mg/l at only four locations on the main channel; at most stations the concentrations were below the test detection limit of 0.01 mg/l. Concentration in the Grand Calumet tributary fluctuated between a high of 0.1 mg/l and below the detection limit of 0.01 mg/l.

Copper was found at all stations, including the tributaries; the highest level was 0.3 mg/l, immediately below the Northside treatment works. Nickel, found at all stations, varied between 0.02 and 0.10 mg/l. Cadmium was detected at or just above its test detection level of 0.01 mg/l at only a few locations on the main channel and the Calumet Sag Channel. Concentrations as high as 0.05 mg/l were detected in the Grand and Little Calumet tributaries, at several points.

A preliminary review of the data obtained for the Lower Illinois River indicated that copper was found at nearly all stations, including tributaries; copper concentrations ranged from traces up to 0.8 mg/l in one tributary, but were below 0.30 mg/l in the main river. Cadmium was found at its test detection limit at only a few stations. Nickel concentrations ranged between the test detection limit of 0.01 mg/l and 0.25 mg/l. Zinc was found at levels up to 0.13 mg/l and chromium was found to vary from the test detection limit of 0.01 mg/l to 0.08 mg/l.

Flow

Figure V-32 presents the averages of the stream flow in the Lower Illinois River during the study periods indicated. The lowest flows, which occurred in July 1962, were from 6500 cfs to 13,000 cfs; the November 1961 flows were between 8500 and 27,000 cfs; the March flows were between 26,000 and 57,000 cfs; and the April flows were between 19,000 and 74,500 cfs.

The flows in the Upper Illinois River system for the periods of study have been tabulated in Tables IX-4 through 13.

Organic Investigations

Investigation of the organic loadings in the Upper Illinois River System began in June 1962 with the installation of carbon filters at the inlet structure at Wilmette and at Lockport. The primary reason for using the presence of persistent organic chemicals for measuring water quality of the area is based on the fact that many of the nation's streams and other water resources have evidenced an increasing pollutional load of organic contaminants in recent years. (6) Because of the heavy concentration of industries that discharge wastes in this watershed, it was assumed that organic contaminants would be a significant part of the total pollutional load discharged into these streams. Additional organic contaminants may also reach the streams by surface run-off, contributing insecticides, pesticides, herbicides and other agricultural chemicals.

These organic substances are only partially removed by ordinary methods of water treatment and, although they may be degraded to a certain extent through biological action, dilution, and settling, a considerable concentration can reach the consumer in drinking water. Organic contaminants are significant in the evaluation of water quality because of their effect on fish and other aquatic life; the production of tastes and odors; and their possible toxicity to humans. (7) Concentrations at levels considered toxic for humans have not been reported in past studies. However, there is a potential hazard to health which cannot be discounted despite the lack of information on the possible effects, immediate or long-term, of even small amounts of these materials on the health of consumers. A principal objective in a control program is to detect undesirable contaminants in water before they reach concentrations that may be harmful, and to work out suitable methods of removing such contaminants. Organic contaminants known to be toxic have been isolated and recovered in waters; among these are DDT, nitriles, ortho-nitrochlorobenzene, dieldrin, and phenyl esters. In addition, many other organic chemicals of synthetic origin have been isolated qualitatively.

Early studies have shown that a few micrograms per liter of organic contaminants can affect the quality of drinking water by causing objectionable tastes and undesirable odors.(8) (9) These findings have led to the adoption in the U.S. Public Health Service Drinking Standards a maximum allowable concentration of 0.2 mg/l of chloroform extractable material in finished waters. (10)

Studies are now being conducted by GLIRBP Laboratories at special sampling points to determine the organic pollutional trends on the Illinois River System. Since this work has only recently begun, relatively few samples have been processed. It is significant, however, that early data resulting from these sampling stations show trends similar to those at the Peoria Station of the National Water Quality Network. The comparative data are shown in Table V-1a and b.

Methods

The methods employed in the determination of organic contaminants in this study are essentially the same as those described by Middleton, et al.(11)

Because of the low concentrations of certain organic materials in water, ordinary analytical methods have been impractical in measuring quantities present. As a consequence, the carbon adsorption technique was developed and is now widely used. This procedure collects and concentrates the organics from a large volume of water, approximately 5,000 gallons, onto a bed of activated carbon. The property of adsorption by carbon of many types of organic materials is particularly advantageous in this procedure. After the carbon containing the adsorbed sample is dried under carefully controlled conditions, it is then extracted with chloroform. Excess chloroform is distilled off and a weighable residue of mixed organic contaminants is left. This residue is called the Carbon Chloroform Extractables (CCE). Further extraction of the carbon is done with ethyl alcohol which removes the more polar organic substances. This residue is called the Carbon Alcohol Extractables (CAE).

It should be pointed out that the carbon does not adsorb all organic material present in water, nor do the solvents desorb or recover all the materials adsorbed. The technique, therefore, cannot be considered a measure of complete organic content. Studies (12) have shown that adsorbed materials can be recovered in a range of 50% to 90%, and that results from samples run in replicate agree within ± 10%. Though the technique is limited in determining "total organic content" it does provide the following:

1. A relative measure of the pollution load due to a class of organic materials not measured by other analytical methods.

2. The knowledge of undue stress on a water from most organic industrial contaminants, particularly synthetic chemicals.

3. Materials that can be subjected to physical, chemical, and physiological tests.

4. A means of determining the relative cleanliness of a stream over a definite period.

Following the extraction and weighing of the gross extractables of chloroform and alcohol, group separations of the chloroform extract were made from the mixed residue on the basis of solubility differences. These groups include either insolubles,water solubles,weak acids,neutrals,and basic materials.The neutral components were further separated by chromatographic means into aliphatic, aromatic and oxygenated fractions. Infrared adsorption curves were also run on selected fractions. The findings are reported in Table V-1a and b. The data from the Peoria station, also included in this table, are taken from tests performed earlier under the National Water Quality Network. Figure V-31 shows the average concentration of organics in parts per billion on a comparative basis, at the three selected stations during the period studied. Also shown is the ratio of chloroform extractables to alcohol extractables.

Discussion of Results

The average chloroform extractables (Table V-1a) recovered at the Wilmette sampling station was about 33 micrograms per liter (ppb). This is characteristic of waters where industrial pollution is light or non-existent. At the Lockport station, downstream from numerous industrial plants, the CCE increased to an average of 190 micrograms per liter. This closely approached the maximum allowable limits. The average of 72 micrograms per liter reported at Peoria probably resulted from degradation of organic products and through dilution by the various tributaries. Another significant finding in the Peoria data is the relative increase in the oxygenated fraction, which in this case is 79% of the neutral fraction, while at Lockport the oxygenated fraction is only 25% of the neutral fraction. This clearly indicates an "aging" of the pollution at Peoria due to a longer traveling distance from point of origin.

The fractional components into which the chloroform extractables have been separated (Table V-1b) and their significance is discussed briefly as follows:

1. Ether Insolubles

   This group, usually a brown humus-like powder, is composed to a large extent of carboxylic acids, ketones, and alcohols of complicated structures.

2. Water Solubles

   The compounds present in this group are largely simple molecules such as hydroxy acids, alcohols, etc., whose probable origin is the oxidation of hydrocarbons, or the residue of natural oxidation processes.

3. Weak Acids

   This group is removed from ether solution by sodium hydroxide, a strong base. It is generally characterized by presence of compounds whose properties are weakly acidic. Among these would be phenols, certain enols, imides and sulfonamides.

4. Strong Acids

   Occurring in this fraction are usually the acids of the carboxcylic group, e.g. acetic, butyric, salicylic, benzoic and higher homologues of this nature. It is significant that these compounds are used frequently in industrial processes.

5. Bases

   This group is characterized by the strongly basic alkyl amines and the less basic aryl amines. Included would be such compounds as hydrazine, methylamine, pyridine, pyrrole and other heterocyclic types which are analogous in that each has a trivalent nitrogen. A high concentration of this fraction is of great significance in producing tastes, odors, or even toxicity.

6. Neutrals

   This fraction generally contains compounds which show neither basic nor acid properties. Among this group are the aromatic and aliphatic hydrocarbons, aldehydes, ketones and products of esterification. This group can be separated into subgroups by chromatographic means as follows:

(a) Aromatics

The materials in this group are principally the aromatic derivatives of coal tar such as benzene, toluene, xylene, aldrin, nitro-chlorobenzene and others. These compounds have great industrial use and their presence in water in large quantities can be significant. Many of these toxic materials have been isolated from some of the nation's rivers. (13)

(b) Aliphatics

This portion contains the straight chain petroleum type of hydrocarbons whose source is usually the petroleum industry.

(c) Oxygenated Compounds

These are generally hydrocarbons that have undergone oxidation into aldehydes, ketones and esters. While many of these compounds result from long exposure of the pollution to chemical forces some are from direct discharges into the stream.

Alcohol Extracts

The alcohol fraction generally consists of polar substances, such as the synthetic detergents, carbohydrates, proteins and other natural products. This fraction is not broken down further because the products present in this fraction can be better determined through conventional methods of analysis.

Losses

As was stated earlier in this report the method used in this experiment does not provide 100% recovery of organic materials. Some of the material is naturally lost in transferring for the various separations and the other is lost because of the extremely volatile nature of some organic components.

Summary

In this investigation on the Illinois River Basin, it is demonstrated that organic contaminants are being carried in the streams and can be detected by the carbon adsorption technique. The number of samples studied thus far, however, will not warrant the drawing of definite conclusions regarding the extent of pollution. Further, studies over a longer period of time are being carried out. It is also expected that the analytical methods now used will be supplemented by refinements which may give a better identification of substances found.

Radiological Investigations

A preliminary investigation of the existing radiological contamination of the Upper Illinois River System has been initiated. Potential sources of radioactive contamination have been identified, information has been assembled on levels of radioactivity and waste flows, and samples from this river system have been collected for analysis. The Radiochemistry Laboratory was established in July of 1962. Samples had been analyzed previously by the Public Health Service, the Illinois State Board of Health, Argonne National Laboratory, Armour Research Foundation, and Dresden Nuclear Power Station. This report includes results from these sources as well as results from the Project Radiochemistry Laboratory.

Significance of Radiological Contamination

Radiological contamination of the environment is of great interest because of increasing public health concern over the long term effects of radiation levels and the fact that expanding production and use of atomic energy will inevitably increase the amount of radiation escaping to the general environment.

When radioactive wastes are discharged to the environment they are not absorbed in the environment in harmless fashion. Even though decay and dilution may occur, radioactive wastes may be reconcentrated physically, chemically and biologically so that the radioactive concentration can be increased as it passes through the environment to the point of human contact.

Contamination of surface water by radioactive materials can result in human radiation exposure through the use of the water as a source of municipal water supply, through the consumption of fish from a contaminated stream or through the consumption of agricultural crops irrigated by such water.

It is generally agreed that all unnecessary human exposure to radiation is undesirable and should be prevented. However, if the benefits of atomic energy are to be utilized then some radiation exposure is inevitable. The National Committee on Radiation Protection (NCRP) has for many years recommended limiting standards for maximum permissible exposure. (14) The values recommended by the NCRP are for occupational exposure. Although the Council recognized that standards for exposure to the radiation worker should be reduced by appropriate factors to establish standards for exposure to the general population, they did not establish these values. The Federal Radiation Council (FRC) was established in 1959 to provide a federal policy on radiation exposure. To date, the FRC has issued three reports (15) (16) (17) which together provide the basic framework of radiation protection standards. These reports establish radiation protection guides (RPG) for the general population. Included in these guides are established specific ranges for daily intake of Iodine-131, Strontium-90, Strontium-89, and Radium-226 within the following criteria:

Range 1; Daily intakes not expected to result in any appreciable number of individuals in the population reaching a large fraction of the RPG.

Range 2; Daily intakes resulting in average exposure to population groups not in excess of the RPG. Such intakes call for active surveillance of the environment and routine control.

Range 3; Daily intakes would be presumed to result in exposures exceeding the RPG if continued for a sufficient period of time. Such results call for careful evaluation and, if necessary, positive control measures.

The daily intake ranges for each of the four radionuclides are shown in Table V-2. These represent the most significant radionuclides but are not the only ones of concern. The environment contains radioactivity from naturally occurring minerals in the earth's crust, from peaceful uses of atomic energy, and from fallout from the testing of nuclear weapons. Fallout is a complex mixture of radioactive fission products with a wide variation in activity.

These various radionuclides can enter the body by several pathways. Combinations of intake from air, water and food may occur; consequently, the use of the RPG must take into account the relative contribution of each source to the total intake. This makes the establishment of a concentration value for any one medium such as water, a very difficult task.

The Public Health Service Drinking Water Standards have received widespread use by various regulating agencies. The radioactivity standards for drinking water are generally accepted as the criteria for evaluating the condition of untreated water for all uses, and are used as the frame of reference for this report. Following is an abstract of the PHS Drinking Water Standards of 1962. (10)

"Approval of water supplies containing radioactive materials shall be based upon the judgment that the radioactivity intake from such water supplies when added to that from all other sources is not likely to result in an intake greater than the radiation protection guidance recommended by the Federal Radiation Council and approved by the President. Water supplies shall be approved without further consideration of other sources of radioactivity intake of Radium-226 and Strontium-90 when the water contains these substances in amounts not exceeding 3 and 10 micromicrocuries per liter, respectively. When these concentrations are exceeded, a water supply shall be approved by the certifying authority if surveillance of total intakes of radioactivity from all sources indicates that such intakes are within the limits recommended by the Federal Radiation Council for control action."

"In the known absence* of Strontium-90 and alpha emitters, the water supply is acceptable when the gross beta concentrations do not exceed 1000 micromicrocuries per liter. Gross beta concentrations in excess of 1000 micromicrocuries per liter shall be grounds for rejection of supply except when more complete analyses indicate that concentrations of nuclides are not likely to cause exposures greater than the Radiation Protection Guides as approved by the President on recommendation of the Federal Radiation Council."

*"Absence is taken here to mean a negligible small fraction of the above specific limits, where the limit for unidentified alpha emitters is taken as the listed limit for Radium-226."

Sampling Stations

The sampling stations used for radiological investigations were the same as those used for physical and chemical investigations. These stations are listed in Tables IV-1, a-h.

Sample Collection

A special collection of samples was made for the Radiochemistry Laboratory in August and September 1962, since it was not in existence at the time samples were collected for the chemical and physical studies. Water samples were collected at mid-stream and mid-depth. Algae samples were collected from the surface of pilings and rocks at various locations in the river. Bottom muds were collected with an Ekman or Petersen Dredge.

Laboratory Procedure

Radiological determinations were made at the Project laboratory. The determinations were made under the supervision of an experienced radiochemist. Analytical procedures followed the methods described in Standard Methods for the Examination of Water and Waste Water (1) and the Radionuclide Analysis Laboratory Manual of the Public Health Service(18).

Water and bottom mud samples were prepared on two inch diameter cupped aluminum planchets. Algae samples were ashed and prepared on similar stainless steel planchets. Suspended solids were separated by membrane filter, transferred and burned with Ethyl Alcohol. All planchets were dried and fixed when necessary with lucite in acetone.

Counting was done in a windowless internal proportional counter (Nuclear Chicago D48) with a two inch lead shield and automatic sample changer (NC Model C210 Special), combined with an NC 202 Scaler and Hewlett Packard 560A Digital Recorder. All samples were counted for thirty minutes (three 10 min. counts) and corrections were made for geometry (G), backscatter(B), self-absorption (A), sample volume (V), and background using the general equations:

Net cpm/GBAV 2.22 = gross radioactivity, uuc/l ± C.E.

where: C.E. (± uuc/l) = $1.96\ (cpm_s/t_s + cpm_b/t_b)^{\frac{1}{2}}/\text{GBAV } 2.22$

where: cpm_s = counts per minute sample
cpm_b = counts per minute background
net cpm = $cpm_s - cpm_b$
t_s = counting time sample
t_b = counting time background

Additional determinations from the Illinois Department of Public Health follow the same methods. Results from Argonne National Laboratory follow the methods described in TID-4500, 16th Edition, AEC Research and Development Report.

Sources of Radioactive Wastes

Potential sources of radioactive wastes which could reasonably be expected to find their way into the Illinois River System can be grouped in two categories: A. Nuclear Reactors, B. Radioisotope Users. The former is the more significant from the standpoint of radiological water pollution. There are three installations in this category in the area of concern: The Argonne National Laboratory, The Armour Research Foundation, and the Dresden Nuclear Power Station. Data on the nuclear reactors at these locations are given in Table V-3.

Results of Analyses

Results of gross radiation analyses of the Illinois River System are shown in Table V-4. Highest levels of activity in water and bottom mud samples were found in the North Branch of the Chicago River, the Grand Calumet River, the Little Calumet River, the Illinois River at Dresden Dam and the Sangamon River. The highest gross beta activities found in water samples (total of dissolved and suspended) were found at stations GC 331.1, GC 326.6, IR 271.6, and Sangamon 102.4. The results were 153, 73, 94 and 132 uuc/l respectively, and are not in excess of the 1000 uuc/l limit for gross beta activity in the known absence of Strontium 90 and alpha emitters. Some of the alpha results in water samples exceed 3 uuc/l, which is the limit for Radium 226 in water, and most of the samples exceed 10 uuc/l of beta activity which is the limit for Strontium 90. The laboratory was not equipped to run specific radiochemical analysis on these samples and was therefore unable to demonstrate that the samples were below the levels established for Radium 226 and

Strontium 90. Station IR 271.6 is the first station below the Dresden Nuclear Power Station which is at the confluence of the Kankakee and Des Plaines River. A comparison of the total Beta activity at IR 271.6 (94 uuc/l) with the activity at the last two stations above it, DP 277.5 (3.4 uuc/l) and Kankakee 278.7 (44 uuc/l) shows the effect of the reactor effluent on the river.

Since water samples indicate only the amount of activity present at the time of collection, it is of interest to note the results obtained from bottom samples and algae samples. These samples will give some indication of the general levels of activity over a period of time. Because these samples are selective and represent only certain isotopes which have been present and because they accumulate these particular isotopes, they are difficult to interpret. The accumulation, however, is directly dependent upon the presence of these isotopes in the water over a given period of time.

It is interesting to note, in Table V-4, that one of the two highest beta activities in bottom muds of 370 uuc/gram was found at the same station which exhibited the highest water sample beta activity. The other bottom mud sample which had 370 uuc/gram coincided with station NB 333.4 which had the second highest beta activity in algae. Many of the algae samples had beta activities between 200 and 800 uuc/gram.

These results do not reflect the location of expected sources of significant wastes. Since these samples are from a moving stream and with the exception of two stations, only one or two sample collections are represented here, the results cannot be used to pinpoint such locations. They do indicate, however, that radioactive materials exist in the system and more study should be undertaken to determine the significance of these materials.

A discussion of the major sources of radioactive wastes and the results of analysis from other agencies follows.

A. Argonne National Laboratory

Argonne National Laboratory is a research and development laboratory operated by the University of Chicago under a contract for the AEC. It is located near Lemont, Illinois, in a relatively high population density area.

The Laboratory conducts a research program of broad scope, much of which is associated with nuclear reactor fuels. In addition to operating reactors shown in Table V-3, significant quantities of liquid radioactive wastes of wide variety are produced.

The Laboratory is equipped with a large well-designed and well-operated waste treatment facility. High level wastes are concentrated and transported to Oak Ridge for burial. Low level wastes are transported to the waste treatment facility in containers. No radioactivity is permitted in the laboratory drains. The systems used are described in open literature. (19) In the handling of radioactive wastes every effort is made to see that no radioactivity enters the Des Plaines River beyond that allowed by NBS Handbook 69. (14)

A record of the discharge of radioactivity from this facility after treatment is shown in Table V-5.

The effluent from Argonne National Laboratory is discharged to Sawmill Creek, a small stream that runs through the Laboratory grounds and flows into the Des Plaines River. Table V-6 shows the effect of the discharge on existing levels in Sawmill Creek. Comparison of the total alpha activities with uranium concentrations shows that the alpha activity added to the creek by the waste water was due principally to natural uranium. The waste water added an average of about 22 micromicrocuries of uranium per liter or about 0.1% of the MPC for natural uranium. Small amounts of plutonium and thorium were also found below the outfall. The alpha activities due to these elements are shown in Table V-7.

The total beta activities in Sawmill Creek are given in Table V-8. Beta activity both above and below the outfall reflects the presence of fission products from nuclear weapons test. Samples taken below the site show an average increase due to waste of 20 micromicrocuries per liter. The individual beta emitters are shown in Table V-9 and are considerably less than their MPC values. Tables V-10 and V-11 indicate that this waste has little effect on the Des Plaines River. In general, then, under normal operating conditions, the radioactivity added to the river by Argonne National Laboratory is not significant at the present time.

B. Armour Research Foundation

Armour Research Foundation is located in a high population density area in Chicago five miles south of the loop and two miles west of Lake Michigan. Armour operates a low power level (75 kw) homogeneous solution type reactor for industrial research. The reactor is fueled with a uranyl sulfate solution containing 850 grams of U-235. (20) Continuous fission product removal from the fuel solution is required. This process results in the accumulation of high level liquid wastes which are stored in steel containers and shipped to Argonne National Laboratory for disposal.

The reactor is located below the level of the sewer system and all discharges must be pumped to waste. Low level wastes are retained in large stainless steel tanks and after analysis are discharged to the City of Chicago sewer system.

Past records indicate an average activity discharge of 10 millicuries per year of beta emitters with only trace amounts of alpha activities.

C. Dresden Nuclear Power Station

The Dresden Nuclear Power Station, located 47 miles southwest of Chicago is the nation's largest all-nuclear power plant. Dresden is a dual cycle boiling water reactor employing 145,000 lbs. of enriched U-238. The plant was completed in 1960 and full power operations began in 1961. (21)

As liquid wastes are generated they are collected and analyzed to determine appropriate treatment. Liquid wastes discharged from the plant after treatment average 5,000 to 7,000 gallons daily with a residual activity averaging 30 mc/day. This discharge is added to the 163,000 gpm cooling water flow before discharge to the Illinois River. The permissible waste discharge from the reactor was established by a permit issued by the Illinois State Sanitary Water Board on August 15, 1960. Under this permit the maximum discharge allowed depends on concentrations observed in the Illinois River below the station at Morris, Illinois. Permissible discharge concentrations are computed each month for the following month by the State as shown in Table V-12 wherein the discharge concentration permitted is 100 micromicrocuries per liter minus the preceding twelve month average concentration observed at Morris.

It is expected that 1.1 million gallons of radioactive liquid wastes will be discharged annually at rated capacity. (21) (22) About 0.2 million gallons of concentrated wastes from the demineralizer system will be stored annually in a steel tank housed in an underground concrete vault. Up to 1,200 curies of activity may be contained in this concentrated solution. The accidental release of this amount of stored material, an extremely remote if not non-existent possibility, would of course, result in very high levels in the Illinois River.

It can be concluded that under normal operating procedures and the controls established by the State of Illinois, the radioactivity added to the Illinois River by Dresden will be well within the limits presently considered acceptable.

D. Radioisotope Users

Production and use of radioistopes has increased steadily since they were first released for general use in 1946. The radioisotopes are licensed for use and regulated by the AEC for medical, educational and industrial uses. It is estimated that 97% of the total isotope activity shipped by the AEC is used as sealed sources. (23) Sealed sources are designed so that leakage of material is prevented. The bulk of remaining isotopes in use have half-lives of less than 30 days and are used chiefly in medical diagnosis and therapy as well as in industrial development and research. Some of this material can be expected to find its way into the sewers; however, the amount would be small. Of 250 AEC licenses in Illinois nearly half are located in Chicago. Half of the Chicago licenses are for material in sealed sources. A summary of unsealed sources appears in Table V-13.

It is not possible to determine from this information how much of this activity reaches the sewer system since much of it is utilized or stored and is either discharged to the sewer slowly or after a period of significant decay. If we were to assume that all of this activity reached the sewer at full strength and was discharged uniformly throughout the year, we would expect an approximate activity concentration of 200 micromicrocuries per liter to result. Actually, of course, a considerably lower concentration would be expected.

In order to obtain an indication of the amount of activity in Chicago's sewage, samples have been taken from each of Chicago's three major treatment works. All samples were taken over a 24 hour period and composited prior to analyses. Gross alpha and beta results are summarized in Table V-14. The alpha activities are not significantly higher than those found in the water supply. The slightly higher beta activities can be related to the much greater solid content per liter of sewage as in the same volume of water. The radioisotope usage in Chicago was not readily detectable in the waste effluents sampled.

REFERENCES

1. *Standard Methods for the Examination of Water and Waste Water*, 11th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation (1960).

2. *Water Quality Criteria*. State Water Pollution Control Board, Sacramento, California.

3. The Relation of Surface Activity to the Safety of Surfactants in Foods. Food Protection Committee - National Academy of Sciences, National Research Council Pub. 463, Washington, D.C. (1956).

4. Freeman, S., et al. The Enzyme Inhibitory Action of an Alkyl Aryl Sulfonate and Studies on Its Toxicity When Ingested by Rats, Dogs, and Humans. *Gastroenterology*, 4: 332-343 (1945).

5. Sawyer, Clair N. Fertilization of Lakes by Agricultural and Urban Drainage. *Journal New England Water Works Ass'n*, 61-2: 109-127.

6. Annual Compilation of Data, October 1, 1959-Sept.30, 1960. National Water Quality Network, U.S. Dept. of HEW, PHS.

7. Rosen, A.A. and Middleton, F.M. Chlorinated Insecticides in Surface Waters. *Analytical Chemistry*, 31: (Oct.1959).

8. Ruchhoft, C.C., Middleton, F.M., Branis, H. and Rosen, H.A. Taste and Odor Producing Components in Refinery Gravity Oil Separator Effluents. *Ind. & Eng. Chemistry*, 46:284 (1954).

9. Middleton, F.M., Grant, Wallace and Rosen, H.A. Drinking Water Taste and Odor Correlation with Organic Content. *Ind. & Eng. Chemistry*, 48:268-274 (1956).

10. 26 Federal Register, 6737, July 27, 1961; Amendments Federal Document 62-2191, March 6, 1962.

11. Middleton, F.M., Rosen, A.A. and Burttschell, R.H. Manual for Recovery of Organic Chemicals in Water. R.A. Taft Sanitary Engineering Center, PHS (1957).

12. Hiler, E.A., et al. Relative Efficiencies of Organic Contaminant Removal. R.A. Taft Sanitary Engineering Center, unpublished data, (Dec. 1961).

13. Middleton, F.M. and Lichtenberg, J.J. Measurements of Organic Contaminants in the Nation's Rivers. *Ind. & Eng. Chemistry*, 52: (June 1960).

14. *Handbook 69*. National Bureau of Standards, U.S. Government Printing Office, (June, 1959).

15. Background Material for the Development of Radiation Protection Standards. Staff Report No. 1, Federal Radiation Council, U.S. Government Printing Office (May 13, 1960).

16. Background Material for the Development of Radiation Protection Standards. Staff Report No. 2, Federal Radiation Council, U.S. Government Printing Office (September 1961).

17. Health Implications of Fallout from Nuclear Weapons Testing through 1961. Staff Report No. 3, Federal Radiation Council, U.S. Government Printing Office (May 1962).

18. Radionuclide Analysis of Environmental Samples. Technical Report R-59-6, Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio (1959).

19. Rodger, W.A., Fineman, B. *Nucleonics* 9: 50-61 (1951).

20. Supplementary Description and Analysis of a Solution Type Reactor for Armour Research Foundation. Armour Research Foundation Report NAA-AER-1135 (June 1958).

21. Annual Report to Congress of the Atomic Energy Commission for 1960. U.S. Atomic Energy Commission, U.S. Government Printing Office (January 1961).

22. Nixon, V.D. A Review of Dresden Nuclear Power Station. Ger-1506 General Electric Co., San Jose, California.

23. Hearings Before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Industrial Radioactive Waste Disposal, I:140, 708; III:2488, U.S. Government Printing Office (1959).

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VI BIOLOGICAL INVESTIGATIONS

Introduction

Seasonal studies were made throughout the Illinois River system to determine the kinds and numbers of stream bottom-dwelling animals, the species and abundance of attached plants, and the kinds and populations of plankton algae.* Data were obtained from the laboratory examination of the various samples collected during the period July, 1961 through June, 1962. Collections of bottom-dwelling animals and attached plant life were made during July-August,1961; October-November, 1961; and February, 1962. Water samples were collected for plankton algae determinations throughout this same stream section from July, 1961 through June, 1962. In addition, special studies included: a survey of the Calumet River system during February and March, 1962; investigations of the flood plain lakes in the lower part of the river system; and exploratory investigations of the benthic fauna downstream from Peoria. These data are summarized in this report and the biological condition of the subject streams in the Illinois River system is evaluated.

Significance of Biological Information

The kinds and numbers of living plants and animals inhabiting a particular stream area reflect the quality of the water that has passed over this area for an extended period of time. Some plants and animals are capable, by virtue of physiological features or living habits, of withstanding polluted conditions and multiply rapidly when competition with less tolerant forms is eliminated. Examples of pollution-tolerant animals are the sludgeworms, bloodworms, leeches, and pulmonate snails that exist in the decaying organic sediment which builds up from the settleable organic solids present in most waste discharges. As conditions favoring these tolerant organisms develop, the more sensitive animals, such as the mayflies and caddisflies, disappear from the community. Ultimately, a population consisting of only one or two species makes up the fauna of the stream bottom. (1)

A benthic population consisting of many kinds of organisms with low numbers of each species is typical of unpolluted streams.(2) Although some of the pollution-tolerant kinds might form part of such a community, they would be a minority. When a single species dominates the population to the exclusion of organisms intolerant of low dissolved oxygen conditions and

*This and other technical terms are defined at the end of this Chapter.

organically overloaded water, the stream is considered severely degraded. Degradation is extreme when streams become so heavily loaded with putrescible materials as to effect complete oxygen depletion so that only air-breathing animal forms can exist. The introduction of toxic wastes and settleable solids, as well as of oxygen-consuming materials could also alter the composition of the community by destroying the sensitive forms and giving more living room to the tolerant kinds. A balanced population would not be re-established automatically by the sudden return to optimum water quality conditions, because the lengths of the life cycles of the organisms vary from weeks to years.

The attached plants (algae and fungi) are also subjected to the waters flowing through their living area. In addition, they are not always found on the stream bottom. In clear water, growths can exist on submerged objects but, as turbidities increase, the algal growths, requiring light, develop nearer the surface. When light transparency is further reduced, the plants favor only the substrata where air, water, and shore meet. Where this stream condition exists, the organisms are exposed not only to the water in the stream but to materials on the surface, such as oil slicks, scums, and floating debris. Thus, the abundance and kinds of plant life are influenced by the quality of the water and the floating materials.

The tolerances of algae to pollution are not as well defined as for the benthic fauna. However, some of the species are known to prefer organically enriched waters and some are known to be intolerant of organically polluted waters.

Plankton algae are microscopic, chlorophyll-bearing plants suspended in the water. Unlike the bottom-dwelling animals and attached plants, they do not represent the biological condition at a given stream area because they are transitory and subject to currents. However, they are an important constituent of the stream because they represent a basic link in the food chain and, through photosynthesis, provide oxygen for the minute animals upon which fish and other aquatic life feed. To a degree, the plankton algae indicate the quality of the water in that the kinds and numbers of algae present depend on the chemical and physical composition of the water in which they originated and in which they dwell.

Algae, like all green plants, require nutrients for growth. Besides many trace elements, algae take up measurable amounts of nitrogen and phosphorus. The density of algae in the water is dependent upon several factors, including the concentration of nutrients. All other factors being favorable, the higher the concentration of nutrients, the greater will be the density of algal growth. (3)

The benthic organisms, attached plants, and the plankton algae not only reveal the quality of the water; they are important agents of self-purification. If organic loading, toxic or inhibitory wastes reach concentrations sufficient to hinder the growth and propagation of these organisms, the natural purification rate is slowed. As a result, the recovery process of the stream is extended farther downstream. (4)

Methods

Field Procedures

All samples of bottom fauna were collected from Ekman and Petersen dredges. The Ekman dredge is a trip-spring device which samples 36 square inches of the bottom to a depth of one to six inches. The Petersen dredge is a much heavier sampler which will collect two-thirds of a square foot of the stream bottom to a depth of one to four inches. A minimum of three dredgings were made at each stream station, usually in a transect. The dredged bottom mud was sifted through a 30-mesh sieve to remove the finer particles and then preserved with formalin.

Specimens of attached filamentous algae were collected from substrata such as buoys and channel walls and preserved with formalin. The plankton algae samples were collected by the aquatic sampling personnel, preserved with formalin, and submitted to the laboratory. Field observations, including odor and consistency of the bottom muds, weather, floating materials, and unusual conditions were recorded.

Laboratory Procedures

The bottom fauna collections were washed free of formalin, sifted, and the various animal forms picked from the remaining detritus. The organisms were then sorted by kinds, counted and reported as numbers of individuals per square foot of stream bottom. (5)

The attached plant life (periphyton) was examined microscopically and identified to genus. Only the predominant organisms are reported.

The clump count method was used to determine the kinds and numbers of plankton algae whereby a microscope counting cell holding one milliliter of water was scanned in such a way that 1/20 of the cell was counted. (6) The organisms were identified to genus and recorded as numbers per milliliter.

Discussion of Findings

Bottom-dwelling Animals

All stations on the Illinois River system from the inlet structures of Wilmette, Chicago Harbor, and Calumet Harbor to downstream IR 166.2 were biologically degraded (Tables VI-1, VI-2, VI-3). Only NS 340.7 near Wilmette, and the Kankakee River station (IR 280.0) bore any semblance to a biologically balanced stream. Severe biological degradation was apparent from NS 336.9 downstream, including CH 326.9 in the Chicago River; and degradation was extreme in the reach downstream from the West-Southwest Sewage Treatment Plant. Only pollution-tolerant kinds of benthic organisms were found from NS 336.9 to IR 166.2.

However, a more varied benthic fauna at IR 263.5 indicated improvement. There was a decided tendency toward recovery in the lower part of the Illinois River to IR 166.2 as shown by the increased variety of bottom fauna with fewer individuals of each kind.

Slight seasonal variations in numbers of organisms were found, but the stream reaches having lesser numbers of organisms during one season were similarly affected during other seasons. These differences, therefore, were attributed to temperature changes in the water. During the winter months, colder water slowed biological activity, particularly the propagation of bacteria, protozoa and other organisms responsible for the breakdown of organic solids. This, in turn, reduced the oxygen consumption so that sufficient dissolved oxygen was present for the existence of larger populations of bottom-dwelling animals.

During the Summer and Fall 1961 surveys, the entire Calumet River and Cal-Sag Channel sections were biologically depressed. Industrial wastes, such as iron oxides and petroleum, were evident in the bottom samples from stations throughout this river system. No benthic organisms were found in the bottom mud at GC 325.8 on the Grand Calumet River. At the other stations large populations of sludgeworms were taken and, except for the pollution-tolerant fingernail clams collected in the Little Calumet River (LC 322.4), no other kinds of bottom-dwelling animals were found. The February, 1962 investigations yielded greater variety in kinds of organisms because of colder water and subsequent decreased activity by the primary agents of "stream purification" mentioned above.

Attached Algae

During the 1961 surveys, attached filamentous algae were scraped from substrata at each sampling station. The kinds of organisms comprising these samples were those usually associated with organically enriched streams. The various genera collected at each station are recorded in Table VI-4, and the tolerance to pollution is reported except where information regarding tolerance is lacking. In the Cal-Sag Channel the growths were either slight or non-existent due to oil slicks on the surface of those streams. No attached plant growths were collected during the February, 1962 survey because of the ice cover.

As a polluted stream progresses from its zone of degradation to its recovery zone, one of the most striking aspects of the biota is the luxuriant growth of filamentous green algae that covers submerged projections. Although attached algae were present in the upper river, no abundant growths were observed in the Illinois River until IR 232. Downstream from IR 232 there were heavy growths, especially in the Peoria Pool (IR 178.0-IR 166.2) where Cladophora was the predominant organism. Cladophora is an algal form typical of nutrient-rich lakes and streams.

Plankton Algae

The plankton algae data are reported for the period, July, 1961-June, 1962 inclusive. The seasonal averages by major artificial groupings, the totals for each of the stream stations, and the predominant genera are recorded in Table VI-5. The total counts are presented graphically in Figure VI-2.

The nutritional effects of wastes discharged in the Chicago area are manifested in the gradual rise from low algae counts below the Cal-Sag and Dresden Pool segment of the river to high concentrations farther downstream. Although these important agents of stream purification are sometimes objectionable in numbers as high as those reached at IR 166, their presence indicates the progress of recovery and may signal decreased bacterial concentrations.

Knowledge of the kinds and numbers of algae also provides information regarding water quality. Algal forms, such as the diatom Cyclotella and the blue-green Anacystis, increase in numbers in stream reaches subjected to organic wastes. These are genera known to favor an organically enriched medium, and were the predominant algal forms in stations downstream from

DP 286.5. Their numbers increased continuously to the farthest downstream station (IR 166). Conversely, the diatoms Tabellaria, Asterionella, and Fragilaria, and others typical of Lake Michigan which are carried into the system at the Wilmette inlet structure (NS 340.7), exemplify algae that do not tolerate polluted conditions. They will not survive in a heavily polluted stream, and did not occur abundantly in samples collected downstream from DP 286.5.

Total plankton algae counts by seasons are illustrated graphically in Figure VI-2. The Fall 1961 and Spring 1962 results were nearly parallel, but the Summer 1961 and Winter 1962 counts were widely divergent. The steady decrease downstream during the Summer of 1961 indicated a process of recovery in the stream, but there was no such rise during January-March 1962. Algal growth and reproduction are retarded in the cold water and subdued light of winter. The recovery process is likewise slowed. Therefore, polluted conditions existed over a longer reach of the stream in winter than during the warmer season.

Physical Observations

As each station was sampled during the three seasons, conditions of the water surface and stream bottom were recorded. A summary of these observations are tabulated elsewhere in this report. Oil slicks, slime, debris, and sewage solids were present on the surface at most of the stations from NS 336.9 to IR 271.5 and throughout the Calumet River system. Dredging revealed oily wastes in many of the samples of bottom deposits from NS 336.9 and CA 333 downstream as far as IR 271.5. Evidence of iron oxides and various unidentified inert materials was apparent at Calumet River stations, particularly at CA 333.0 and GC 325.8.

The effect on the biota of the various wastes is not clearly defined, but some of them are probably inhibitory as shown by the smaller numbers of organisms where bottom deposits were sufficient to support large populations of sludgeworms, and dissolved oxygen values were adequate for these very tolerant animals.

The three seasonal studies involved boating between stations. Thus, the entire Illinois River system was travelled several times. During these trips, continual observations were made and unusual conditions noted. Sewage solids were not common downstream from IR 271.5, but oily wastes were occasionally observed as far downstream as IR 194.

Calumet Area Biological Survey

During February and March, 1962, a survey was made covering 14 stations in the Calumet area of Northeastern Illinois and Northwestern Indiana. Sampling was restricted to bottom-dwelling animals, since the ice cover precluded sampling for attached algae. The findings of that survey are reported in Table VI-3b. The methods in the field and laboratory were identical with those employed in studies of the Illinois River system.

A striking contrast between the Little and Grand Calumet Rivers was observed. Although both streams were considered biologically degraded, the Little Calumet River yielded bottom-dwelling organisms other than sludgeworms. Polluted conditions in this river were due to sanitary sewage and there was little evidence of industrial wastes.

In the Grand Calumet River, however, both sewage solids and industrial wastes were observed. The Grand Calumet was found to be biologically barren at three of the stations sampled and only a few sludgeworms existed in the bottom deposits at the other stations. Petroleum wastes, minute iron particles, fibers, and sewage solids were observed in this stream. Undoubtedly, the industrial wastes exerted an inhibiting or toxic influence strong enough to suppress the establishment of sludgeworm communities. The organic bottom deposits and the presence of dissolved oxygen, even though slight, would ordinarily create a favorable habitat for these very tolerant organisms. (7)

Flood Plain Lakes

The biological condition of the flood plain lakes along the lower Illinois River system was evaluated by a series of bottom fauna surveys. Those lakes were Lake Senachwine and Sawmill Lake near Henry, Douglas Lake near Chillicothe, Quiver Lake near Havana and Muscooten Bay near Beardstown. All of these lakes are large and have an average depth of only one to three feet. The bottom was silt and ooze and very little rooted vegetation was observed.

Bottom dredgings at Lake Senachwine, Sawmill Lake, Douglas Lake and Quiver Lake yielded only sludgeworms and bloodworms. Muscooten Bay was considerably improved over the above-mentioned lakes in that fingernail clams, operculate snails and mayfly larvae were present along with many sludgeworms. Muscooten Bay, however, receives water directly from the Sangamon River via a channel from the Sangamon, whereas the other lakes have direct connections with the Illinois River and are influenced by no other streams. It appears that these lakes connected with the Illinois River are subjected to siltation from the Illinois during periods of high water and are continuously becoming more shallow.

The records at the office of the Chautauqua Wildlife Refuge near Havana, indicate that Lake Chautauqua which is only connected to the Illinois River during floods has been reduced in depth by siltation several feet in the last 30 years.(8)

All of the lakes observed were very turbid, having transparencies in a range of 6 to 12 inches as measured by a Secchi disc. These high turbidities are largely responsible for the lack of rooted vegetation, since the sunlight required by young plants cannot penetrate.

Benthic Fauna of the Lower Illinois River

The biological condition of the Illinois River from Peoria downstream did not show any marked change until IR 113, where sludgeworms ceased to be the predominant organisms and the pollution intolerant operculate snails and unionid clams were dredged from the stream bottom, (Table VI-3b).

Farther downstream sludgeworms again occurred, but the numbers of kinds of other organisms increased and the pollution-intolerant unionid clams were common. The more varied populations of benthic fauna and the occurrence of pollution-intolerant forms indicate that the Illinois River improved biologically from the vicinity of IR 113 downstream to IR 21. Evidence of materials deleterious to the stream biota, such as oil and other industrial wastes, were rare and the dredgings from the bottom of the stream did not have a sewage odor as did many of the bottom samples at stations farther upstream.

Definitions of Terms

Algae - Comparatively simple floating or attached plants, containing photosynthetic pigments. A majority are aquatic and many are microscopic in size.

Benthic - Adjective referring to aquatic organisms growing in close association with the bottom.

Benthos - All bottom-dwelling organisms.

Biota - The plant and animal life of a region.

Bloodworm - A common name for insect larvae of the Family Tendipedidae. This family includes the aquatic midges with the exception of the Ceratopogonidae.

Chlorophyll - Green plant pigment associated with photosynthesis.

Ecology - The study of interrelations between organisms and their environments.

Fauna - Animal life.

Fingernail Clams - Small clams of the Family Shpaeriidae.

Flora - Plant life.

Fungi (sing. Fungus) - Simple plants without chlorophyll, including the bacteria. The simpler forms are one-celled; the higher forms are branching filaments.

Macroscopic - Large enough to be clearly observed by the naked eye.

Mayfly - Aquatic insect of the Order Ephemeroptera.

Microscopic - Too small to be clearly observed by the naked eye.

Ooze - Soft, black, non-granular, slimy bottom material.

Operculate Snail - A gill-breathing snail.

Organism - Any living thing.

Periphyton - A miscellaneous assemblage of plants growing upon free surfaces of objects submerged in water.

Photosynthesis - Process carried on in light by plants containing chlorophyll which enables them to combine water, carbon dioxide, and other inorganic essentials to form sugar and other carbohydrates, and to release oxygen into the water.

Phytoplankton - Plant plankton.

Plankton - Minute, unattached aquatic plants and animals, usually microscopic, drifting with the current.

Pulmonate Snail - A lung-breathing snail.

Sludgeworm - A common name for a group of various kinds of Oligochaetes, which are segmented worms found in aquatic environments and achieving their greatest abundance in areas of organic enrichment.

Substratum - Surface upon which an organism rests or moves, or the solid material within which it lives in whole or in part.

Toxicity - Degree to which a substance is poisonous.

Unionid Clam - A large bivalve, belonging to one of the clam families other than the Family Sphaeriidae (fingernail clams).

Zooplankton - Animal plankton.

REFERENCES

1. Tarzwell, C. M. and Gaufin, A. R. Some Important Biological Effects of Pollution often Disregarded in Stream Surveys. Purdue University Engineering Bulletin, Proceedings of the Eighth Industrial Waste Conference. Purdue University, Lafayette, Indiana (1953). p. 303 and pp. 306-307.

2. Bartsch, A. F. and Ingram, W. M. Stream Life and the Pollution Environment. Reprinted from Public Works Publications, Ridgewood, N.J.

3. Welch, P. S. Limnology. McGraw-Hill Book Co., New York (1952). p. 261.

4. Reid, G. K. Ecology of Inland Waters and Estuaries. Reinhold Publishing Co., New York (1961). p. 317.

5. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, New York (1961). pp. 572-586.

6. Plankton Identification and Control. Course Manual, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio (1961). BI.MIC. pp.1-3.

7. Goodnight, C. J. and Whitley, L. S. Oligochaetes as Indicators of Pollution. Purdue University Engineering Bulletin, Proceedings of the Fifteenth Industrial Waste Conference. Purdue University, Lafayette, Indiana (1961). pp. 139-142.

8. French, W. Chautauqua Wildlife Refuge. Private Communication. Havana, Illinois (1962).

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VII BACTERIOLOGICAL STUDIES

Introduction

The chief bacterial parameters presented herein to express the sanitary quality of the waters investigated are the densities of coliform bacteria and fecal streptococci. The coliform bacteria have long been used in the United States as indicators of fecal contamination of water. To provide additional bacterial information of sanitary significance a recently improved test for determining the density of fecal streptococci has been included by the Great Lakes-Illinois River Basins Project.

Definition of Coliform

The coliform groups of bacteria are defined as including all of the aerobic and facultative anaerobic, Gram-negative, non-sporeforming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35° C. This group is synonymous with the "B coli" or "coli-aerogenes" group, as described by earlier standard texts. (See Standard Methods for the Examination of Water and Wastewater(1), p.494.)

Significance of Coliform Bacteria

The significance of coliform organisms to water quality is that the origin of most of this group of bacteria is the intestinal tract of warm-blooded animals, including man. Consequently, the presence of coliform organisms in a body of water is interpreted as an indicator of contamination of the water by fecal matter. Since the contamination of water by fecal matter is one avenue of transmission of certain water-borne diseases to humans, coliform organisms are utilized as indicators of possible pathogenic contamination. Increasing densities of coliform bacteria found in water are, therefore, related to the degree of pollution of enteric origin and to increasing health hazard to those exposed to the water.

Definition of Fecal Streptococci

Streptococci are Gram-positive cocci occurring in chains, composed of varying number of cells. These organisms may be parasitic or saprophytic. Several species abound in the intestinal contents of man and other animals. In most earlier references, those originating from fecal matter or sewage have been referred to as the enterococci, with specific reference to *Streptococcus faecalis* and its varieties and *Streptococcus durans*. While these latter forms are the predominant streptococcal species in human feces, they also occur in the feces of other animals and fowls. However, other streptococcal species may predominate in the feces of different animals, depending on the kind of animal (cow, pig, horse, fowl). Among these streptococci may be *Streptococcus bovis*, *Streptococcus equinus*, and biotypes not easily placed in any one group.

The term fecal streptococci as used in these present studies, includes any species of streptococci commonly present in significant numbers in the fecal excreta of humans or other warm-blooded animals. (2)

Significance of Fecal Streptococci

The fecal streptococci, which are also enteric organisms abounding in the intestinal tracts of all warm-blooded animals, likewise indicate the presence of fecal matter in water. The fecal streptococci may, at times, indicate the presence of fecal matter in water more specifically than the coliform bacteria. This is because some of the coliform group may be found in nature (soil, etc.) and may multiply in water or soils; whereas the fecal streptococci generally do not multiply in bodies of water.

In human feces, there are, on the average, three times as many coliform bacteria as fecal streptococci. In polluted waters, the coliform/streptococcal ratio varies widely, depending on the source of pollution (domestic, or packing house wastes, etc.), its age, and other environmental conditions.

Tests for fecal streptococci are not proposed as a replacement for coliform determinations. The demonstrated presence of fecal streptococci may, however, confirm the supposition that coliform organisms which are found in a certain water sample are of fecal origin. The tests may thus be of value where there is a question concerning the sanitary significance of coliform bacteria.

Method of Detection of Coliform Bacteria and Fecal Streptococci

There are two standard procedures for determining coliform density. One is the most probable number procedure, long used in this field. It results in a number which is a statistically-derived representation of the density. The other is the membrane filter procedure, more recently developed, which is a direct colony count. The membrane filter procedure, as it is described in Standard Methods (1) (pp. 508-513) was the procedure used in the present survey.

The direct colony count by the membrane filter procedure was also used for the enumeration of the fecal streptococci.

Standard Methods (1)(pp.523-526) lists the tests for the enterococcus group on a tentative basis. The test procedure for the fecal streptococci used in the present study is based on the procedure developed at the Robert A. Taft Sanitary Engineering Center by Kenner, Clark, and Kabler(3), and is referred to as the "Fecal Streptococcus Test."

Geographical Area Surveyed

The geographical limits of the waters investigated, with the sampling points, are shown in Fig. IV-1, IV-2, IV-3, and described in Chapter IV.

Method of Data Presentation

All coliform and fecal streptococcus results in the present report are expressed as the geometric mean per 100 ml of original sample.

Upper Illinois River System

Sample Collection and Compilation of Data

Detailed information on the densities of coliform bacteria and fecal streptococci occurring in the Upper Illinois River System are presented in Table VII-1 and Figures VII-1 and VII-2. Table VII-1 and Figure VII-1 show 1961 summer conditions and 1962 winter conditions for the main reaches of this system (see map of sampling points, Figure IV-1). Likewise Figure VII-2 shows 1962 winter findings in the investigation of the Calumet Rivers.

In the summer study for coliform bacteria, samples were collected generally on a daily basis throughout April-May, June, July, and August 1961. The fecal streptococcus determinations on the summer study were obtained only in September 1961.

The coliform results from the summer study are presented both as monthly geometric means and also as geometric means derived from the total number of samples comprising the summer study for each point (referred to in Table VII-1 as the 4-month geometric mean).

General Summary

The water entering at Wilmette (NS 340.7) and the Chicago River (CH 326.9) inlets is of relatively good quality, usually carrying only moderate or light densities of coliform bacteria and fecal streptococci. The inlet of the Cal-Sag system at its mouth (CA 332.7) is frequently subject to intermittent pollution resulting from reversal of flow direction.

As the water moves down the waterway, the coliform density increased from 230 per 100 ml to 390,000 in fifteen river miles. The fecal streptococci increased from 320 to 3,400 in eleven river miles. (Both coliform and streptococci levels just cited were from the summer months investigation). The pollution level indicated by these bacterial findings at all sample points (except the inlets NS 340.7 and CH 326.9) within the Upper Illinois River System is such that danger to health must be presumed to exist in any use of, or contact with, these waters located in the Metropolitan Chicago Area.

While the exact points of pollution were not located precisely, they appeared to be distributed throughout the drainage basin indicating numerous points of entry. Sharp rises in coliform and fecal streptococcus counts are also encountered downstream from the Northside, Stickney, and Calumet Sewage Treatment Plants, as would be expected of unchlorinated sewage treatment plant discharges.

The winter coliform densities encountered were generally lower than those of summer at each corresponding point, whereas the reverse was generally true of the fecal streptococci; that is, the winter values for the streptococci were at times somewhat higher than those of the summer determinations. These findings may be due to the differences in the survival characteristics of the two types of organisms when released into bodies of water.

Coliform and Fecal Streptococcus Results

The bacteriological findings from the investigations of the Upper Illinois River System are described below in relation to the various reaches of the river system.

North Shore Channel: Table VII-1a
Sampling Point NS 340.7

Coliform Density: During the sampling periods of April-May, June, July and August, average coliform densities of 150, 160, 400 and 600 per 100 ml, respectively, were encountered. The 4-month geometric mean based on a total of 71 samples was 230 per 100 ml. In the winter period the mean coliform density was 52.

Fecal Streptococcus Density: Fecal streptococcus mean values for summer and winter were 320 and 100 respectively. These densities would represent the condition of the lake waters entering the river system.

Sampling Point NS 338.6

Coliform Density: Higher counts were observed at the next sampling point, NS 338.6, during the summer months with monthly means of 4,100; 3,100; 4,600 and 1,300 per 100 ml. The 4-month geometric mean was 3,500 per 100 ml, with a mean value of 1,800 per 100 ml for the winter conditions.

Fecal Streptococcus Density: Fecal streptococcus mean values for summer and winter were 80 and 120 respectively.

Sampling Point NS 336.9

Coliform Density: This sampling point manifested an additional increase with mean monthly values of 17,000; 6,200; 7,600; and 1,600 per 100 ml and a 4-month geometric mean of 8,200 per 100 ml. No winter data are available due to icing conditions.

Fecal Streptococcus Density: The fecal streptococcus mean value for summer was 88 per 100 ml. Up to this point these increases can be attributed to sewage pollution of unknown origin.

Sampling Points NS 334.9 and NS 333.4

Coliform Density: Sampling point NS 334.9 which is the point just below the Northside Sewage Treatment Works, and point NS 333.4 further downstream show sharp increases in coliform densities with mean monthly values ranging from 110,000 to 280,000 per 100 ml, representing increases of 10 to 175 times at point NS 333.4 over the corresponding monthly mean value at point NS 336.9, above the treatment plant. The 4-month geometric means were 160,000 per 100 ml. at point NS 334.9 and 104,000 per 100 ml. at point NS 333.4.

The winter densities at points NS 334.9 and NS 333.4 were 100,000 and 140,000, respectively.

Fecal Streptococcus Density: The mean values for summer conditions were 2,200 at point NS 334.9 and 1,200 at point NS 333.4. Winter densities were 5,200 and 5,400 per 100 ml. respectively.

North Branch, Chicago River: Table VII-1b
Sampling Points NB 333.4, NB 331.4,
NB 329.0 and NB 325.8

Coliform Density: At point NB 333.4, located above the juncture of the North Shore Channel and North Branch of the Chicago River, the monthly means for April-May, June, July and August were 33,000; 100,000; 140,000; and 72,000 per 100 ml., with a 4-month geometric mean of 71,000 per 100 ml. Below the juncture of the North Shore Channel and North Branch of the Chicago River, pollution levels progressively increase at the next three sampling points, as is shown in the 4-month geometric mean of 160,000; 220,000; and 390,000 for sampling points NB 331.4, NB 329.0 and 325.8, respectively. The July monthly mean of 570,000 per 100 ml. at point NB 325.8 was the highest density encountered at these three points (Table VII-1b).

Winter coliform densities at points NB 333.4, NB 331.4, NB 329.0 and NB 325.8 were 21,000; 63,000; 44,000; and 18,000 respectively.

Fecal Streptococcus Density: The fecal streptococcus densities at points NB 333.4, NB 331.4, NB 329.0 and NB 325.8 as shown by the summer investigations were 830, 1,600, 3,400, and 2,200 respectively.

Winter densities for fecal streptococci were 5,200, 5,100, 3,400, and 1,900 respectively.

Chicago River: Table VII-1b
Sampling Points CH 326.9 and CH 325.8

Coliform Density: At the two sampling points located on the Chicago River, the following monthly means of coliform densities were obtained: 480, 1,400, 630, and 400 per 100 ml.

for the months of April-May, June, July, and August respectively, and 5,300, 18,000, 11,000, and 7,000 per 100 ml. at the second point. The 4-month densities were 680 and 9,100. CH 326.9 is the point nearest to the inlet from Lake Michigan and represents the bacterial quality of the incoming water.

During the winter study,mean values of 200 and 640 per 100 ml. were observed.

Fecal streptococcus Density: At point CH 326.9 the fecal streptococcus density was 200 per 100 ml. for the summer study and 120 per 100 ml. during the winter study. At point CH 325.8 the streptococcus density was 780 in summer and 100 in winter.

South Branch, Chicago River: Table VII-1c
Sampling Points SB 324.3 and SB 322.8

Coliform Density: Below the juncture of the North Branch and the Chicago River, designated as the South Branch, the two sampling points are located at milepoints SB 324.3 and point SB 322.8 respectively. Points SB 324.3 and SB 322.8 showed a 4-month geometric mean of 200,000 and 280,000 per 100 ml. in the summer study. The highest single monthly mean at either of these two points occurred in June at point SB 322.8 with a density of 410,000 per 100 ml.

During the winter study, point SB 324.3 had a mean of 14,000 per 100 ml., and point SB 322.8 had a mean of 13,000 per 100 ml.

Fecal Streptococcus Density: In the summer study, fecal streptococcus densities of 720 and 610 per 100 ml. were obtained at points SB 324.3 and SB 322.8. In the winter study, the fecal streptococcus densities were 700 and 1,700 respectively. The lower levels observed at these points reflect the effects of dilution of the grossly contaminated waters at NB 325.8.

Sanitary and Ship Canal:
Table VII-1d, VII-1e
Sampling Points SS 320.0, SS 317.3, SS 314.0, SS 307.9, SS 304.1, SS 300.5, SS 292.1, and SS 291.1

Coliform Density: The drainage area beginning at point SS 320.0 and extending to point SS 291.1 for 28.9 miles, is designated as the Sanitary and Ship Canal. The coliform levels at points SS 320.0 and SS 317.3 are approximately the same as in the South Branch, Chicago River, at point SB 322.8.

The coliform peak in the Sanitary and Ship Canal occurs at point SS 314.0 with the August monthly geometric mean of 950,000 per 100 ml. Monthly geometric means for April-May, June, and July were 250,000; 440,000; and 620,000. Point SS 314.0 is the first sample point below the Stickney Sewage Treatment Works. At point SS 307.9, the coliform density increased each month during the study period: 320,00 in April-May; 470,000 in June; 570,000 in July; and 900,000 in August. A progressive decrease was generally observed from point SS 304.1 through point SS 292.1, reaching the lowest value of 61,000 (4-month geometric mean for the Sanitary and Ship Canal). The Cal-Sag Channel enters the main stem immediately below SS 304.1.

Fecal Streptococcus Density: During the summer study, the fecal streptococcus densities showed a general, progressive increase between points SS 320.0 and SS 307.9 (1,500 to 8,100 per 100 ml.) followed with progressive decreases downstream with a density of 520 at point SS 291.1. In the winter studies, the highest fecal streptococcus density in the Sanitary and Ship Canal was encountered at point SS 314.0 (5,800 per 100 ml.) with progressive decreases downstream in the canal to the level of 580 at point SS 291.1.

Calumet-Sag Channel and Calumet Rivers
Calumet River and Grand Calumet River: Table VII-1f
Sampling Points CA 332.7, CA 328.1, CA 327.0 and CrC 325.8

Coliform Density: Three sampling points were located on the Calumet River: point CA 332.7, CA 328.1 and CA 327.0. The study showed these points to have respective coliform densities of 2,000, 5,400, and 4,000 per 100 ml. (4-month geometric mean). CA 332.7 is located near the mouth of the Cal Sag System and represents the condition of incoming waters from the lake. Point CA 327.0 is located at the mouth of Lake Calumet. The Grand Calumet River joins the Calumet River below point CA 327.0. CA 328.1 is intermediate between these two points. One sample point on the Grand Calumet River, GC 325.8, had a coliform density of 2,300,000 (4-month geometric mean), with the highest monthly geometric mean occurring in June (3,000,000). This extremely high coliform density of the Grand Calumet River may be the result of discharges from several towns located in this area.

The winter coliform densities for points CA 332.7, CA 328.1, CA 327.0 and GC 325.8 were 270; 1,300; 990; and 27,000 respectively, per 100 ml.

Fecal Streptococcus Density: During the summer study, fecal streptococcus densities of 140, 480, 120 and 1,200 were detected with the corresponding points showing winter levels of 130, 4,700, 180, and 9,100 at CA 332.7, CA 328.1, CA 327.0 and GC 325.8, in that order.

Little Calumet River: Table VII-1f
Sampling Points: LC 322.4, LC 320.1, LC 320.2

Coliform Density: Sampling points on the Little Calumet River portion of the Cal-Sag System with their coliform densities (4-month geometric mean) are: Point LC 322.4 with 40,000 per 100 ml.; point LC 320.1 with 51,000; and point LC 320.2 with 150,000. The Calumet-Sag Channel forms a junction with the Little Calumet River between sampling points LC 320.1 and LC 320.2.

The Calumet Sewage Treatment Plant is located near sampling point LC 322.4. The effluent from this plant is divided, with 80% flowing into the Little Calumet River between points LC 322.4 and LC 320.1, and 20% flowing into the Calumet-Sag Channel at the junction of the channel with the Little Calumet River.

Calumet-Sag Channel: Table VII-1g
Sampling Points: CS 317.9, CS 314.9, CS 311.5, CS 308.4 and CS 304.1

Coliform Density: The coliform densities (4-month geometric means) were: CS 317.9, 120,000; Point CS 314.9, 190,000; Point CS 311.5, 110,000; Point CS 308.4, 98,000; Point CS 304.1, 23,000.

The winter densities for these same points were 90,000, 57,000, 47,000, 23,000, and 18,000 per 100 ml.

Fecal Streptococcus Density: Points CS 317.9, CS 314.9, CS 311.5, CS 308.4, and CS 304.1 showed the following respective fecal streptococcus densities in the summer study: 2,100, 1,300, 520, 460, and 260 per 100 ml. Under winter conditions, the fecal streptococcus levels were as follows: point CS 317.9-5,000; point CS 314.9-3,500; point CS 311.5-2,200; point CS 308.4-1,500; and point CS 304.1-[illegible].

The Calumet-Sag Channel forms a junction with the Sanitary and Ship Canal just below point SS 304.1.

Sanitary and Ship Canal: Table VII-1d, VII-1e
Sampling Points SS 300.5, SS 292.1, and SS 291.1

Coliform Density: The monthly coliform densities at SS 300.5 ranged from 130,000 to 260,000 per 100 ml; the 4-month geometric mean was 200,000. The winter density at this point was 41,000.

As was pointed out earlier, the coliform densities progressively decreased between sampling points SS 304.1 and SS 292.1. The 4-month geometric means for SS 296.2 and SS 292.1 were 110,000 and 61,000 per 100 ml., respectively. The winter densities were 41,000 and 14,000, respectively.

An increase in coliform densities was observed at SS 291.1. The 4-month geometric mean at this point was 72,000. The winter density was 20,000.

Fecal Streptococcus Density: The summer streptococcus densities at points SS 300.5, SS 296.2, SS 292.1, and SS 291.1 were 330, 970, 420, and 520, respectively. The winter densities were 2,600, 2,000, 500, and 580 per 100 ml., respectively.

The increases in coliform and fecal streptococcus densities reflect some addition of pollution to the stream in this area, which is adjacent to Lockport, Illinois.

Des Plaines River: Table VII-1h
Sampling Points DP 292.7, DP 285.8, and DP 278.0

Coliform Density: The upper point DP 292.7 had a 4-month geometric mean coliform density of 4,200, and is the only point sampled on this river above its junction with the Sanitary and Ship Canal. The first sample point below the junction was DP 285.8 with a 4-month geometric mean of 79,000 coliform bacteria per 100 ml. At DP 278.0 the count was 64,000 coliform.

The Des Plaines flows through the city of Joliet, Illinois, with sampling point DP 285.8 located just below the city.

The winter coliform densities at points DP 292.7, DP 285.8, and DP 278.0 were 7,300, 32,000, and 23,000 per 100 ml.

Fecal Streptococcus Density: The streptococcus densities (4-month geometric mean) for points DP 292.7, DP 285.8 and DP 278.0 were 580; 910; and 430, and in the winter study were 480; 2,500; and 990 respectively.

Illinois River: Table VII-lh
Sampling Points KR 277.5 and IR 271.5

Coliform Density: The coliform density of the Illinois River below the mouth of the Kankakee River at IR 271.5 had a 4-month geometric mean value of 17,000 per 100 ml., with a winter density of 8,700.

A single sampling point on the Kankakee River, KR 277.5 was 20,000 per 100 ml. (4-month geometric mean), and 5,000 per 100 ml. for the winter mean.

Fecal Streptococcus Density: The summer streptococcus density for point IR 271.5 was 98 and at point KR 277.5, 290 per 100 ml. The winter means were 420 IR 271.5 and 560 KR 277.5.

Calumet Drainage Basin Study

The water quality of the Calumet Drainage Basin was studied in the period February 8, 1962, to March 2, 1962. Samples were collected once a day, almost daily.

Several streams form a network of channels which are connected to Lake Michigan at several points. (See Figure IV-2). These streams are the Grand Calumet River, the Little Calumet, the Indiana Harbor Canal. Hart Ditch and Thorn Creek empty into the Little Calumet River. The Calumet Sag Channel also is connected to the Little Calumet.

The bacterial results are shown in Table VII-li. Heavy pollution was indicated at most of the sampling points, with coliform counts in the range of 100,000 - 300,000 per 100 ml. The fecal streptococcus densities were also elevated at these points, ranging from 20,000 to 120,000 per 100 ml. The lowest coliform counts occurred on that portion of the Calumet River receiving Lake Michigan water diverted to the Calumet Sag Channel. These were at LC 327.0, with a coliform density of 5,500 per 100 ml., and a fecal streptococcus density of 1,100 per 100 ml. Point LC 322.4 had a coliform density of 8,500 and fecal streptococcus density of 1,200 per 100 ml. The sampling point at GC 326.6 showed the highest counts of all: coliform 300,000 per 100 ml., and fecal streptococci, 120,000 per 100 ml.

From the results of this study, it is obvious that the waters of the Calumet Drainage Basin are heavily contaminated.

Lower Illinois River System

Coliform and fecal streptococcus densities for the **Lower** Illinois River System are shown in Tables VII-2a and VII-2b respectively and in Figures VII-3 and VII-4, respectively. Information from three separate studies is included. These are November, 1961 (autumn conditions), March, 1962 (winter conditions), and July, 1962 (summer conditions). Each of these studies was of approximately one month duration.

General Summary

In general, the pattern for the three seasons on the Illinois River is the same, with the coliform values increasing at River Miles IR 263.5 and IR 252.7 followed by reduction in numbers at points further downstream until the City of Peoria is reached. The effect of the Peoria wastes is reflected in the highest coliform values on the Illinois River at IR 143.2, with **mean** coliform densities of 38,000, 17,000, and 210,000 per 100 ml in November, March, and July. The coliform densities at stations below IR 143.2 showed some reduction in density, but remained at higher levels than at stations immediately above Peoria.

In a comparison of the variations due to season, the coliform densities were generally rather constant. They did not manifest significant increases or decreases at most of the sampling points except at IR 143.2 which showed a substantial rise during the July study period.

The findings based on fecal streptococcus densities support the coliform findings, showing similar rises and decreases in the mainstream. In several of the tributaries (marked "T") the streptococci exceeded the coliforms. This may be a reflection of run-offs from farm lots with concentrations of live stock or fowl.

Coliform and Fecal Streptococcus Results

Sample Point 280.8(T) - DuPage River

The DuPage River is tributary to the DesPlaines River above the junction of the DesPlaines and Kankakee River, which unite to form the Illinois River. The DuPage at point 280.8 showed coliform levels of 5,300, 17,000, and 14,000 per 100 ml in the November, March, and July studies, respectively. The corresponding fecal streptococcus densities were 460, 15,000, and 1,400.

Sample Point 278.7(T) - Kankakee River

The coliform densities for November, March, and July were 5,400, 13,000, and 16,000, respectively. The fecal streptococcus densities were 690, 16,000, and 1,900, respectively.

Sample Point 271.6(Dresden Dam)

The sampling point on the Illinois River at 271.6 showed coliform densities of 8,200, 9,800, and 28,000 in November, March, and July, respectively with accompanying densities of fecal streptococci of 310, 6,200, and 810.

Sample Point 270.6

The next point downstream on the Illinois River (at 270.6) exhibited coliform densities of 7,300, 14,000, and 27,000, and fecal streptococcus densities of 270, 7,000, and 390 in the November, March, and July studies, respectively.

Sample Point 263.5

Coliform densities showed an increase at this point with 14,000, 20,000, and 32,000 for November, March, and July, respectively. These increases indicate increasing pollution between points 270.6 and 263.5. The corresponding fecal streptococcus densities were 360, 5,200, and 630 per 100 ml.

Sample Point 252.7

The bacterial quality of the Illinois River Water did not manifest significant change in the stretch between 263.5 and 252.7. Coliform densities were 14,000, 11,000, and 21,000; while the fecal streptococcus densities were 390, 6,200, and 200, for November, March, and July, respectively.

Sample Points 246.9 to 166.1

Between sample points 252.7 and 166.1 the coliform densities generally decreased in each of the three studies. Point 166.1, opposite the Peoria water intake, showed coliform densities of 1,300, 780, and 3,500 in the November, March and July studies ,respectively. These densities at this point represent the lowest densities encountered on the Illinois River in these studies. (See Table VII-3a). The fecal streptococcus densities were 210, 840, and 90, at 166.1, in November, March, and July.

In this stretch of river two tributary streams empty into the Illinois River. These are the Fox River (241) and the Vermillion River (236.5). The Fox River showed coliform densities of 4,600, 11,000, and 3,900 in November, March, and July with corresponding fecal streptococcus densities of 840, 6,500, and 2,600. The Vermillion River showed coliform densities of 17,000, 7,800, and 6,200. The fecal streptococcus densities were 4,100, 15,000, and 1,500 in the November, March, and July studies, respectively.

Sampling Points 158.7 to 143.2

The effects of the discharges from Peoria are reflected in the increasing coliform densities in this stretch of the River. In each of the three studies, point 143.2 exhibited the highest coliform densities of all the sampling points located downstream from Peoria on the mainstream. These coliform densities were 38,000, 17,000, and 210,000 in November, March, and July, respectively. In the November and March studies, point 143.2 also exhibited the highest fecal streptococcus densities of points located on the mainstream below Peoria, with densities of 8,200 and 6,900. In the July study the peak in fecal streptococcus densities was 4,000 at point 156.5.

Two tributaries occur in this stretch of the river - Kickapoo Creek and Mackinaw River.

The Kickapoo showed coliform densities of 9,800, 9,600, and 23,000 and fecal streptococcus densities of 4,800, 4,100, and 3,100 for the November, March, and July studies, respectively.

The Mackinaw River showed corresponding coliform densities of 12,000, 7,500, and 6,400 and fecal streptococcus densities of 13,000, 3,900, and 800.

Sample Points 125.8 - 21.7

The Illinois River showed a tendency to reduction of coliform densities from 132.0 to 21.7. However most of the densities were in excess of 10,000 per 100 ml. The July coliform density at 21.7 was 25,000 per 100 ml.

The fecal streptococcus densities were higher for the November and March studies in the lower reaches of the Illinois River (at 78.6-4,000 in November, 1,900 in March, and 190 in July). The July streptococcus density at 21.7 was 240 per 100 ml.

Tributaries in this stretch of the Illinois River are the Spoon River, the Sangamon River, the LaMoine River and Macoupin Creek. These streams showed highest coliform densities in the November study with densities of 19,000, 20,000, 15,000 for the Spoon, Sangamon, and LaMoine Rivers, respectively. The corresponding streptococcus densities were 14,000, 4,100, and 12,000. The lowest streptococcus densities for these streams occurred in July

Conclusions from the Results on Indicator Organisms

Upper Illinois River System

1. With the exception of sampling stations NS 340.9 and CH 326.9, the inlets from Lake Michigan, all sample points showed evidence of excessive pollution, as indicated by the coliform and fecal streptococcus tests.

2. Increasing coliform and fecal streptococcus densities usually indicate increasing sewage pollution.

3. Coliform densities at all sample points, except NS 340.7 and CH 326.9 were such that danger to health must be presumed to exist through any water uses or contact with these waters.

4. While it is impossible to locate all points of sewage influx, they appear to be distributed throughout the drainage basin.

5. Large numbers of coliform and fecal streptococcus organisms are contributed by the sewage treatment works effluents, as evidenced by sharp rises below the North, Stickney and Calumet plants of the Metropolitan Sanitary District.

Lower Illinois River System

1. With the exception of IR 166.1 located near the Peoria Water Intake, all points on the lower Illinois River System showed sustained evidence of excessive pollution, as indicated by the coliform and fecal streptococcus tests.

2. Coliform and fecal streptococcus densities at most sample points were such that danger to health must be presumed to exist in any water uses or contact with these waters.

3. The pollution load of the Illinois River is increased by the discharges from the City of Peoria and all tributaries studied.

Special Investigations

In view of the extensive pollution in the Upper Illinois River System as indicated by the findings from the coliform and fecal streptococcus investigations, a further, more detailed investigation of the actual incidence of certain water-borne pathogens, was undertaken. Among the water-borne disease-producers are the bacterial forms producing typhoid and enteric fever (*Salmonella*), dysentery (*Shigella*), tularemia (*Pasteurella*), and tuberculosis (*Mycobacterium*). Viral forms include *enteroviruses*, among which are the poliovirus and the infectious *hepatitis virus*. One parasitic form is the amoebic dysentary protozoan (*Endamoeba hystolytica*). These special laboratory investigations have been limited to detection of the *Salmonella*-*Shigella* group and the enteroviruses, particularly the polio virus.

Detection of Pathogenic Enterobacteria

Details of the survey program for detection of organisms belonging to the *Salmonella*-*Shigella* group (pathogenic nonsporeforming, Gram-negative rods) are briefly outlined in the paragraphs below.

Definitions

Salmonella. "The salmonella are Gram-negative,nonsporeforming, motile bacilli easily cultivated on ordinary media; they characteristically fail to ferment lactose and sucrose. The different species are closely related antigenically, and these relationships are used as the main criterion in classification. All are pathogenic for man or animals, usually for both. *Salmonella typhosa,* the cause of typhoid fever, is pathogenic only for man; the other salmonella produce disease in man and animals." (4)

Shigella. Organisms belong to the genus *Shigella* are nonencapsulated, nonsporulating, nonmotile gram-negative rods. Different members ferment various carbohydrates. At least one species ferments lactose but only after 2 or 3 days' incubation. Their natural habitat is restricted to the gastro-intestinal tract of primates in contrast with the more ubiquitous distribution of the members of the genera *Salmonella* and *Escherichia*. The various species of *Shigella* are pathogenic for man and represent the etiologic agents of bacillary dysentery-hence the common name of dysentery bacilli.

Significance of Pathogenic Enterobacteria

Water-borne epidemics of enteric fevers have been reduced in frequency to such a point as to be isolated exceptions to the general rule. The water-borne epidemics of typhoid fever, cholera, and dysentery-so common at the turn of the century-apparently became a thing of the past, as modern hygienic principles became established in sanitary engineering practices. However, with increasing population adding greater volumes of domestic sewage, agricultural and certain industrial wastes, and with increasing water usages introducing additional pollution loads, the margin of safety has narrowed for the drinking water industry.

Modern microbiology has shown that enteroviruses are not completely removed by sewage treatment processes and that these same enteroviruses may withstand the drinking water treatment processes now in general use.

Drinking water is only one of many water usages of concern. Other uses such as recreational activities bring the public into intimate contact with natural and public bodies of water. These recreational activities include water sports, swimming, water-skiing, skin-diving, boating, hunting and fishing. General industrial uses include those directly associated with water, e.g., navigation and commercial fishing, etc. The contamination of foodstuffs-fish and crops irrigated by polluted water-are also factors associated with degraded stream and lake water.

Most of the water courses draining inhabited regions are contaminated with human or animal feces. However, pathogenic enteric microorganisms probably do not multiply in the water under normal conditions. They usually disappear from streams in a relatively short time, sooner in some waters than in others, and more quickly in summer than winter. (5)

With the above considerations in mind, the Great Lakes-Illinois River Basins Project undertook a survey localized in the Chicago Metropolitan Area. Raw sewage in the Chicago sewers and sewage treatment plant effluents were analyzed qualitatively for pathogenic enterobacterial content. These findings are summarized in Table VII-3.

Collection of Samples

The first samples were collected in June of 1962. The program continued into the fall of 1962.

Samples were collected by means of Moore Gauze Pads (6) suspended for 3-day periods in the streams and in waters at the treatment plants. The pads were installed at the following points:

North Shore Channel

1. Influent-Northside Sewage Treatment Plant.
2. Effluent-Northside Sewage Treatment Plant.

Sanitary and Ship Canal

3. Influent-Stickney Sewage Treatment Plant.
4. Effluent-Stickney Sewage Treatment Plant.

Calumet Sag Channel

5. CS 317.9
6. Influent-Calumet Sewage Treatment Plant.
7. Effluent-Calumet Sewage Treatment Plant.
8. LC 322.4.

The Moore Gauze Pad method of sample collection was chosen as a means of concentrating the enteropathogenic bacteria which occur at a much lower density than the coliform bacteria and fecal streptococci. This means of sample collection obviates quantification of findings. However, the isolation and identification of enteropathogenic bacteria is sufficient evidence to indicate a public health hazard. No actual quantitative statement regarding the size of infectious doses is available since this factor depends on individual resistance. A small number of microbial cells may at times produce the disease in one person whereas another individual (either through natural means or through artificial immunization) may withstand significantly larger numbers of the same organism.

Method of Detection

The laboratory isolation procedures utilized established cultural and serological techniques as set forth in Identification of Enterobacteriaceae by Edwards and Ewing. (7) The serological findings were confirmed by the Communicable Disease Center, Atlanta, Georgia.

Salmonella-Shigella Results

Of a total of 26 samples, 11 (42%) have yielded Salmonella organisms. The samples were distributed as follows: raw sewage (S.T.P. influent), 13; treated sewage (S.T.P. effluent), 10; river water (points removed approximately 1-2 river miles from the sewage treatment plant outfalls), 3 (See Table VII-3). The frequency of positive findings for salmonella organisms were as follows: 17 strains from raw sewage; 15 strains from sewage treatment plant effluent; and 1 strain from sampling point LC 322.4 on the Little Calumet River.

The species of Salmonella serologically identified were as follows: Salmonella paratyphi B, S. derby, S. montevideo, S. anatum, S. san-diego, S. tennessee, S. senftenberg, S. braenderup, S. infantis, S. oranienburg. Table VII-2 shows the distribution and frequency of isolation of these Salmonella species.

Salmonella paratyphi belongs to the group primarily containing human pathogens producing paratyphoid fever. The other strains are representative of the group naturally pathogenic to animals, but also able to produce disease in man in the form of gastro-enteritis-which is sometimes fatal.

No Shigella have been isolated to date. The Shigella group has rarely been isolated from streams or sewage effluents. However, negative findings do not necessarily indicate its absence because the laboratory isolation media and procedures may not be sensitive enough to detect the organism.

Conclusions

The results indicate that:

(1) the raw sewage in Chicago contains a variety of infectious Salmonella species.

(2) these organisms effectively move through the present sewage treatment process and into the receiving streams.

It is assumed, on basis of these results, that the waters receiving raw sewage discharges are thereby contaminated with these organisms.

Enterovirus Isolations from Sewage and River Water

A special project was initiated in July 1962 to investigate enteroviruses in the water of the Illinois River Basin. This was a cooperative study between the Kansas City Field Station and the Great Lakes-Illinois River Basins Project. From the middle of July to the end of December, 1962, virus isolations have been performed on 162 samples. This report describes the preliminary results of virus isolation and identification.

Definition and Significance of Enteroviruses

According to Bergey's Manual (8), viruses are defined as "etiological agents of disease, typically of small size and capable of passing filters that retain bacteria, increasing only in the presence of living cells, giving rise to new strains by mutation. A considerable number of plant viruses have not been proved filterable; it is nevertheless customary to include these viruses with those known to be filterable because of similarities in other attributes in the diseases induced.... Viruses cause diseases of bacteria, plants and animals."

The term enterovirus refers to a group of viruses which are normally found in the gastointestinal tract of man. It includes the polioviruses, the Coxsackie viruses and the ECHO(enteric cytopathogenic human orphan) viruses. These viruses frequently cause infections in man, particularly during the summer and fall months. Polioviruses are well known for their capacity to cause paralytic and nonparalytic poliomyelitis. Coxsackie and ECHO viruses cause a variety of illnesses, including polio-like disease, pleurodynia (devil's grip), pericarditis, myocarditis, diarrhea, and respiratory disease. The virus may be discharged in the feces of infected persons for a month or longer. The enteroviruses are relatively hardy and can withstand environmental damage. Man becomes infected by ingestion of material contaminated with the virus.

Collection of Samples

Weekly samples were collected from 12 sampling sites in the Upper Illinois River Basin as follows:

North Shore Channel

1. NS 336.9
2. Influent-Northside Sewage Treatment Plant
3. Effluent-Northside Sewage Treatment Plant
4. NS 334.9

Sanitary and Ship Canal

5. SS 317.3
6. Influent - Stickney Sewage Treatment Plant
7. Effluent - Stickney Sewage Treatment Plant
8. SS 314.0

Calumet Sag Channel

9. CS 317.9
10. Influent - Calumet Sewage Treatment Plant
11. Effluent - Calumet Sewage Treatment Plant
12. LC 322.4

The specimens were collected by personnel of the Great Lakes-Illinois River Basins Project, employing the gauze pad technique introduced by Moore (6). The pads were immersed in the sewage or water flow for a period of seven days. The liquids were squeezed from the pads. The samples thus obtained were frozen and shipped to the Virus Laboratory at Kansas City.

Method of Detection

Each sample was prepared by preliminary centrifugations to get rid of gross particles and bacteria. The clarified liquid was concentrated by high speed centrifugation according to the method described by Gravelle and Chin.(9)

Monkey kidney tissue cultures and suckling mice were used for virus isolation. Polioviruses, ECHO viruses and certain types of Coxsackie viruses cause destruction of monkey kidney tissue culture cells. Coxsackie viruses cause illness in suckling mice with characteristic pathologic changes.

Polioviruses were identified by typing with specific poliovirus antisera. Those isolates, not typable by poliovirus antisera, were tested for Coxsackie virus by suckling mouse inoculation. Those viruses which are not identifiable as poliovirus or Coxsackie virus will be studied further. Many of these isolates are probably ECHO viruses or mixtures of different enterovirus types.

Enterovirus Results

Of the 162 samples, 49 were raw sewage, 44 were samples from the effluent outfall, 37 were water samples from the sites above the treatment plants and 32 were water samples from sites below the treatment plants. The frequency of virus isolations by types of sample is shown in Table VII-5 and summarized in VII-4.

Of the 162 samples tested, 76 (46.9 per cent) contained a virus or a mixture of viruses. Eighteen polioviruses were isolated. Six were identified as Type 1, one Type 2, seven Type 3, and four have not been typed. Fifteen of the positive samples contained a Coxsackie virus.

Virus was isolated from 77.6 per cent of raw sewage samples and from 45.4 per cent of water samples obtained at the effluent outfall. Twenty-seven per cent of water samples from sites above the treatment plants contained virus. A similar percentage (25%) of virus isolations were obtained from water samples collected at areas below the treatment plants(See Table VII-5).

The samples were distributed among the various sampling points as follows: NS 336.9, 14; Northside Sewage Treatment Plant Influent, 16; Northside Sewage Treatment Plant Effluent, 16; NS 334.9, 8; SS 317.3, 12; Stickney Sewage Treatment Plant Influent, 16; Stickney Sewage Treatment Plant Effluent, 13; SS 314.0, 12; LC 332.4, 11; Calumet-Sewage Treatment Plant Influent, 17; Calumet Sewage Treatment Plant Effluent, 15; and LC 317.9, 12. Table VII-5 (Col.3) shows that 50% of the effluent samples from the Northside Plant yielded enterovirus, while 46.2% of the effluent samples from the Stickney Plant and 40% of the effluent samples from the Calumet Plant also yielded enterovirus. From these positive effluent samples, the following poliovirus identifications were made: Northside, 1; Stickney, 1; and Calumet, 3. Five poliovirus isolations were made from the stream samples collected either above or below the treatment plants. Eight poliovirus isolations were made from the influent samples. Of the 15 Coxsackie virus isolations, 12 originated in samples collected in relation to the Northside Plant (4 from the stream site above the plant, 5 from the influent samples and 3 from the effluent samples). Of the three remaining Coxsackie isolations, 1 originated from the point above the Stickney Plant and 1 from the Stickney influent. The remaining Coxsackie virus originated in the Calumet Plant influent.

The total number (76) of virus isolations were divided among the three plants and their associated points as follows: Northside, 31; Stickney, 26; and Calumet,19.

The frequency of virus isolations by month of collection is summarized for 138 of the samples, in Table VII-6. Sixty per cent of the samples obtained in July were positive; the frequency of isolations then gradually decreased to 37 per cent in October. Although the number of polioviruses and Coxsackie viruses identified to date is relatively small, it is noteworthy that Coxsackie viruses were most prevalent in July, while polioviruses were most prevalent in August.

Conclusions

The results suggest that water of the Upper Illinois River Basin is contaminated with enteroviruses. The high frequency of virus isolation from the sewage effluent indicates that the sewage treatment facilities are inefficient for elimination of enteroviruses.

Since polioviruses, Coxsackie viruses and ECHO viruses normally multiply in the intestinal tract of man, finding of these viruses in the river waters provides direct evidence of human fecal contamination.

Exposure to these waters can be considered as a hazard to human health.

REFERENCES

1. *Standard Methods for the Examination of Water and Wastewater.* Eleventh Edition. American Public Health Association, Inc. New York, N.Y. (1960).

2. *Recent Developments in Water Bacteriology.* U.S. Department of Health, Education, and Welfare; Public Health Service; Division of Water Supply and Pollution Control; Robert A.Taft Sanitary Engineering Center. Cincinnati, Ohio. (1961).

3. Kenner, B.A.; Clark, H.F.; and Kabler, P.W. Fecal Streptococci. I. Cultivation and Enumeration of Streptococci in Surface Waters. *Applied Microbiology,* 9. No. 1: 15-20 (1961).

4. Dubos, R.J. *Bacterial and Mycotic Infections of Man.* J.B. Lippincott Co., Philadelphia (1958). p. 375.

5. Kabler, P.W.; Clark, H.F.; and Clarke, N.A. Pathogenic Microorganisms and Water-Borne Disease. *Proceedings Rudolfs Research Conference: Public Health Hazards of Microbial Pollution of Water.* Dept. of Sanitation, College of Agriculture, Rutgers University. (1961). pp. 9-56.

6. Moore, B. The Detection of Paratyphoid Carrier in Towns by Means of Sewage Examination. *Month. Bull. Min. Health and Pub. Health Lab. Service,* 7:241 (1948).

7. Edwards, P.R. and Ewing, W.H. *Identification of Enterobacteriaceae.* Burgess Publishing Co., Minneapolis (1962).

8. Breed, R.S.; Murray, E.G.D.; Smith, N.R. *Bergey's Manual of Determinative Bacteriology.* The William & Wilkins Co. (1957). p. 985.

9. Gravelle, C. and Chin, T. Enterovirus Isolations from Sewage: A Comparison of Three Methods. *J. of Infectious Diseases,* 109: 205-209 (1961).

CHAPTER VIII - SPECIAL STUDIES

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VIII SPECIAL STUDIES

This Chapter presents details of special studies carried out in conjunction with basic studies concerning water quality of the Illinois River system. Subsequent sections discuss additional aspects including the quality of incoming diversion water at Wilmette Harbor; influents and discharges from the three major treatment plants of the Metropolitan Sanitary District; the quality and quantity of wastes discharged from storm water overflow outlets of the combined sewer system; an estimation of the depth and extent of sludge or settleable solids deposited in the channels of the Upper Illinois River system; and results of continuous Dissolved Oxygen analyses at three locations. All these studies were found necessary; they provide additional information to support the findings of the basic study.

Quality of Diversion Water at Wilmette

As early analytical results became available it soon was apparent that the BOD of incoming lake water sampled at points of diversion was not representative of unpolluted water. Analytical results obtained from samples taken at NS 340.7 (representing the water entering the Upper Illinois River system) indicated pollution in excess of that expected for Lake Michigan water. To determine the BOD of lake waters adjacent to this inlet, a special study of the quality of shoreline water in the vicinity of the Wilmette inlet was undertaken.

Samples were taken both inshore and offshore for a distance of approximately three miles above and three miles below the inlet. Inshore samples were taken at points shallow enough for surface waves to affect bottom sediment; offshore stations were beyond the point of wave interference on the bottom. The results, using these samples, are presented in Table VIII-1 and Figure VIII-1; they show that the BOD of inshore waters was from two to four times greater than that of the offshore waters. This increase in BOD is attributed to bottom sediment resuspended by wave action. Figure VIII-1 verifies this conclusion since a definite pattern can be seen between the inshore BOD's and inshore suspended solids. As the solids go up, so do the BOD's.

Inspection of the shoreline revealed no apparent sources of pollution such as sewer outfalls or storm water overflows. From the data presented, it was concluded that this increased BOD can be attributed to the presence of increased suspended solids, constantly in suspension due to wave action, whose possible source may be the accumulation of surface debris driven to the shore by wind and wave action. The equivalent PE of incoming lake water was calculated as approximately 35,000 at the average diversion rate of 475 cfs, for this sampling period.

Metropolitan Sanitary District - Treatment Plant Studies

The three Sewage Treatment Plants of the Metropolitan Sanitary District contribute the principal metropolitan waste load to the Illinois River system. Because the volume of these wastes is large, these plants are considered, jointly, as the most important single factor affecting the water quality of the river. Therefore, a study of the water quality of discharges from these plants, and impact of the discharges on the receiving waters, was undertaken. The three plants were studied during two separate periods. The first period was from April 24 through May 21; the second period was from September 11 through September 24, 1961. The extreme rainfall conditions which prevailed during the second period resulted in significant differences between the two study periods.

Description of MSD Plants

The Northside Works is an activated sludge plant with an average design capacity of 250 MGD and a maximum capacity of 375 MGD. It discharges its effluent into the North Shore Channel of the Upper Illinois River system at mile point 336.6.

The Calumet Works is an activated sludge plant with an average design capacity of 136 MGD and a maximum capacity of 210 MGD. It discharges its effluent into the Little Calumet River section of the Calumet Sag Channel at two points, mile point 319.2 and mile point 321.4. The flow is divided approximately 20% and 80%, respectively.

The West-Southwest (Stickney) Works combines two types of sewage treatment plants; the Westside Imhoff Plant and the Southwest Activated Sludge Plant operate together as a unit. This is the largest sewage treatment plant in the world. The Westside Plant is designed for an average flow of 472 MGD and a maximum of 690 MGD. The Southwest Plant is designed for an average flow of 428 MGD and a maximum of 810 MGD. When the two plants are operating as a combined unit, the average design flow is 900 MGD and the maximum is 1,200 MGD. Each plant provides primary treatment to the portion of raw sewage reaching that plant through a combination of interceptor sewers serving different areas of the Metropolitan Sanitary District. The primary treated sewage entered the Southwest aeration tanks; 46 percent came from the Westside Imhoff tanks and 54 percent from the Southwest primary tanks.

The raw sewage flow to the Westside Plant, with the addition of Southwest Plant primary sludge, is settled in Imhoff tanks. The sludge from the Imhoff tanks is dried on sludge drying beds, or is pumped to sludge lagoons or to the Southwest sludge concentration tanks. The Westside Imhoff effluent flows to the Southwest aeration tanks and leaves the Works after secondary treatment via the Southwest effluent sewer. The waste activated sludge from Southwest is concentrated, vacuum-filtered, and dried for storage or shipment.

The raw sewage flow to the Southwest Plant is settled. The settled sludge from the primary settling tanks is transferred to the Westside Plant by the Salt Creek interceptor. The primary effluent, together with the Westside effluent and Northside sludge, is treated by the activated sludge process. The point of discharge of the Stickney effluent is at mile point 315.8 on the Ship and Sanitary Canal.

First Study Period (April 24-May 21, 1961)

Sampling was carried out on a 24-hour basis with grab samples of influent and effluent collected hourly, iced and delivered to the laboratory every eight hours. In the laboratory the samples were composited in eight-hour increments proportional to flow and subjected to immediate analysis.

Data collected from the three plants during this period is summarized in Table VIII-2. This table shows that the total average discharge rate from all plants during the study period was 1238 MGD - very close to the 1286 MGD average design flow of the three plants. The Population Equivalent (PE) of the combined discharges was 969,000 or 78.2 tons of 5-day BOD per day; a contribution of 37.9 tons of dissolved oxygen, daily, is shown. The over-all removal efficiency was 88.8%.

The quality of these discharges is typical of activated sludge plant effluents. The 5-day BOD averages of the discharged effluents ranged between 10.8 and 16.4 mg/l. The pH of the discharges was normal for typical activated sludge plants and the coliform density range was typical of this type of unchlorinated effluent. The DO levels were generally higher than expected for activated sludge effluents but are considered beneficial in view of the low dilution available in the receiving waters.

Second Study Period (September 11-24, 1961)

This study was undertaken to extend the scope of the first study by including tests for additional parameters of water quality. In addition to studies on flow, pH, BOD, DO and coliforms, the influents of the three MSD plants were analyzed for: COD; suspended, settleable and dissolved solids; fecal streptococci. The additional tests on the effluents were: COD; settleable BOD; suspended, settleable and dissolved solids; organic, ammonia, nitrite plus nitrate nitrogen; ortho and total phosphate; ABS; chloride; and fecal streptococci. Sampling procedure was identical to that of the first study.

The results of this study are summarized in Tables VIII-3, -4, -5, & -6. The ranges displayed in these tables emphasizes the effect of heavy rainfall which was encountered during the study period.

Table VIII-3 summarizes the BOD loadings and reductions effected by the three treatment plants. The average discharge rate from all plants during the study period was 1682 MGD which is considerably higher than the average design flow. The population equivalent of the combined discharges was 793,000, or 66.2 tons of 5-day BOD per day. The overall removal efficiency was 87.8%. These findings, when compared to the first study period, show the effect of extreme rainfall conditions on loads received at the plants. For example, the raw PE of the first study period (8,288,000), compared with the PE of the second period (6,504,000) shows that in spite of an increased volume of waste water handled, there was a loss of 1,784,000 PE per day due to storm water overflow or bypassing. Adding this load to the effluent discharge load of 793,000 results in an average PE discharge of 2,577,000. If the average effluent PE of 969,000 observed during the April study is subtracted from this figure, a net loss of 1,608,000 in PE is indicated (presumably as storm water overflow or direct bypass to the receiving stream).

Another observation of interest, shown in this table, is the percentage of total BOD of the effluents that is settleable. This suggests that a further reduction in BOD could be accomplished by additional treatment.

Table VIII-4 summarizes the solids loads received and discharged by the three plants. Eleven hundred ten tons per day of suspended solids were received and 119.1 tons were discharged, resulting in a reduction of 89.3 percent.

The discharged dissolved solids amounted to 3,238 tons per day. This value is a composite of the dissolved solids present in the water supply of Chicago plus that added as sewage. If all of the water pumped by Chicago (MGD) passes through the MSD plants its content of dissolved solids (155 mg/l) will account for 665 tons/day of the dissolved solids in the effluent. The remaining 2,563 tons per day is the load contributed by the industries and population of the MSD.

Table VIII-5 summarizes the other chemical parameters of significance to water quality studied during this period. Of the 41.5 tons of nitrogen discharged, 58 percent, or 24.5 tons, is in the form of ammonia and organic nitrogen. The remainder is oxidized and exists in the form of nitrite and nitrate nitrogen. The oxygen attached to the nitrogen is available to the stream as an additional source of oxygen whenever conditions approaching total depletion of dissolved oxygen are reached. In this form it is an asset, useful in delaying the occurrence of nuisance conditions. The organic and ammonia nitrogen are potential sources of oxygen demand and can account for over five times their weight in oxygen demand if oxidized to nitrate. This potential oxygen requirement can be a heavy demand in downstream reaches subject to nitrification. The combined effect of the total nitrogen discharged, with the phosphate that is present, can result in increased levels of algae and plankton life downstream. This nutrient effect can ultimately cause taste, odor, and increased treatment costs to downstream water users.

The ABS concentration of 1.6 mg/l is considerably above the limits set for drinking water standards by the USPHS (1). Although partial degradation by natural purification processes can be expected, the residue from this concentration of ABS can result in foaming, and unsightly appearance. No conventional method of treatment is currently available to reduce ABS concentrations to acceptable water quality levels.

The average chloride concentration of 58 mg/l discharged by the three MSD plants includes the chloride (7.5 mg/l) present in the water supply of Chicago. The net increase of 50.5 mg/l is equivalent to 314 tons per day added by domestic and industrial wastes discharged to the sewer system. Because chloride can be responsible for objectionable taste in drinking water at high concentrations, and is responsible for increased corrosion to water handling equiment in industrial and cooling uses, control of excessive chloride discharges is a worthwhile practice.

The dissolved oxygen levels contributed by the MSD plants averaged 6.7 mg/l and provided 46.3 tons/day of additional oxygen to the river system. Although this quantity of oxygen is insufficient for the over-all needs of the river system it is a beneficial contribution and should be maintained.

The average pH of the treatment plant discharge (pH 7.5) is typical of activated sludge effluents and, being approximately neutral, is considered satisfactory for discharge to the river system. The pH of the daily discharges did not vary significantly from the average value; therefore, in terms of water quality significance, the pH is not considered a problem.

Coliform and Fecal Streptococcus Determinations

A short term investigation of the coliform and fecal streptococcus density of the influents and effluents of the three sewage treatment plants (Northside, West-Southwest and Calumet) was conducted during the month of September 1961. Samples were collected every four hours to obtain a twenty-four hour study on each of the plants. Data was obtained on total coliform and fecal streptococcus density via direct membrane filter procedure on each of the samples collected. Initial measurements were in terms of numbers per 100 ml. of sample. Total coliform and streptococcus loads for the twenty-four hour period were computed on the basis of flow as determined for eight-hour periods. The average numbers of coliform and streptococci per 100 ml. were similarly determined. The ratio of coliform to fecal streptococci was calculated for each influent and effluent. The summary data are presented in Table VIII-6.

Northside Plant: For the 24-hour period studied, the average coliform density of the influent was 9.9×10^6 per 100 ml., and the fecal streptococcus average was 1270×10^3 organisms per 100 ml. The ratio of coliform to streptococci was 8.0. The effluent coliform average was 0.34×10^6 per 100 ml., and the fecal streptococcus average was 27×10^3 per 100 ml. The ratio of total coliform to streptococci in the plant effluent was 12.7.

The average plant efficiency in terms of coliform reduction was 96.4%, and in terms of fecal streptococci, 97.9%.

Calumet Plant: For the twenty-four hour period studied, the influent coliform average was 8.1×10^6 organisms per 100 ml., and the fecal streptococcus average was 1732×10^3 per 100 ml. The ratio of coliform to fecal streptococci was 4.8. The effluent coliform average was 0.3×10^6 per 100 ml. and the fecal streptococcus average was 52×10^3 per 100 ml. The ratio of coliform to fecal streptococci was 6.6.

The average plant efficiency in terms of coliform removal was 95.8% and in terms of fecal streptococci, 97.0%.

West-Southwest Plant (Stickney): A twenty-four hour study on the West-Southwest plant was completed for the period of September 12 and 13. Because this study occurred during a period of heavy rainfall, an additional twenty-four hour study was carried out on September 20 and 21 in conjunction with similar studies on the Northside and Calumet plants on the same day, when influent flows were not as great.

September 12-13: Since the Stickney works are a combination of two types of sewage treatment plants and provide a common plant effluent into the Illinois Waterway, the influent data was calculated on the basis of combined totals and averages obtained on data from the two separate influents (West and Southwest). The combined twenty-four hour average coliform concentration was 10.1 x 10^6 organisms per 100 ml. and the combined fecal streptococcus average was 2500 x 10^3 per 100 ml. The ratio of coliform to fecal streptococci from the Southwest and West influent was 7.0. The effluent coliform average was 0.11 x 10^6 per 100 ml., the fecal streptococcus average was 59 x 10^3 per 100 ml., and ratio of coliform to fecal streptococci was 1.9.

The average plant efficiency in terms of coliform removal was 99.4%, and in terms of fecal streptococci, 97.6%.

September 20 and 21: The influent coliform average was 40.0 x 10^6 per 100 ml and the combined fecal streptococcus average was 15.5 x 10^6 per 100 ml. The ratio of coliform to fecal streptococci was 2.6. The effluent coliform average was 0.34 x 10^6 per 100 ml. The fecal streptococci average was 140 x 10^3 per 100 ml., and the ratio of coliform to fecal streptococci was 2.4.

The average plant efficiency in terms of coliform removal was 99.2% and in terms of fecal streptococci, 99.1%.

The coliform and fecal streptococci discharges from the three treatment plants show a reduction of 95 to 99%, which is typical of the activated sludge process without chlorination. However, the levels discharged are far above that considered safe for human exposure. The pollution levels indicated by these bacterial findings is such that danger to health must be presumed to exist in any use of, or contact with, these effluents.

Combined Sewer Overflows

Underground storm water drainage in Chicago was inaugurated with the construction of the first city sewer system in 1856. The system was designed to carry both storm water and sanitary sewage to the Chicago River and to Lake Michigan, and served about seven square miles including the present "Loop" area. In the 106 years since 1856, the Chicago combined sewer system has been expanded to include over 3,600 miles of sewers serving 190 square miles with 3.5 million population. Most of the suburban municipalities in the Chicago Metropolitan Area also are served by combined sewer systems which discharge storm runoff into the waterways of the area.

For many years these combined sewers discharged all flows directly to the streams, of which some were tributary to Lake Michigan, and others tributary to the Illinois River. In 1890, the Metropolitan Sanitary District of Greater Chicago was organized and initiated construction of a system of sanitary and combined interceptor sewers serving Chicago and many of the suburbs. The interceptor system is designed to conduct dry weather flows to the various sewage treatment plants operated by the Sanitary District, and to discharge storm runoff through overflow structures and pumping stations, to the Des Plaines, Chicago and Calumet Rivers, the Chicago Sanitary and Ship Canal, and the Calumet Sag Channel.

Storm water overflows to the Des Plaines River follow the natural course of the river to the Illinois River. Storm water overflows to the Chicago River are also tributary to the Illinois River, since the natural direction of flow of the Chicago River has been reversed. The Calumet Sag Channel, completed in 1922 by the Sanitary District, was designed to reverse the flow of the Calumet River from Lake Michigan to the Chicago Sanitary and Ship Canal. This flow is regulated by means of the Controlling Works at Blue Island, except during infrequent heavy storms when runoff threatens to cause flood damage along the Calumet Sag Channel. At such times, the control gates are closed, forcing Calumet River flood flows to Lake Michigan. If storm runoff to Calumet Sag Channel causes the water surface to rise above that of the Calumet River, the control gates may be opened to permit flow out of the Calumet Sag to Lake Michigan, as a flood relief measure. Thus, storm water overflows to the Calumet Sag Channel and Calumet River are usually tributary to the Illinois River but may occasionally go to Lake Michigan. A new lock and control gates have been built in the Calumet River just downstream from the confluence of the Grand Calumet and Little Calumet Rivers. After removal of the old Controlling Works, Calumet Sag Channel flows will be regulated at the new lock.

Pollutional Aspect of Combined Sewer Overflows

The discharge of raw sewage and industrial wastes mixed with storm water during periods of storm runoff constitutes a significant intermittent source of pollution of the waterways in the Chicago area. The physical extent of the problem is indicated by the large number of overflows, approximately 200 on the main channels, and an undetermined number on tributary streams such as the Des Plaines River, the North Branch Chicago River and the Little Calumet River. The locations of the overflows on the main channels are shown on Figure VIII-2.

Pollution of streams in a metropolitan area results in economic loss through curtailment of recreational use of the waterways, increased water treatment costs, reduced property values, corrosion of boats and nearby structures, and, under certain conditions, the loss of industrial development. The esthetic value of the streams is destroyed by unsightly floating material, murky waters and unpleasant odors. The biological life of the stream is adversely affected by low oxygen values resulting from the oxygen demand of sewage and industrial wastes. Pleasure boat operators either avoid the waterways or use them as a means of acess to less polluted waters.

More important, however, is the danger to public health from the pathogenic bacteria and viruses which may be present in raw sewage. Although the concentration of BOD and sewage solids, with exception of the first flush, may be reduced by dilution during runoff periods, the pathogens remain a serious menace to any public use of the streams receiving these discharges.

The total pollution load contributed to Chicago area watercourses by storm water overflows from the combined sewer systems has not been determined by field measurement. The percentage of the annual sanitary and industrial waste flow spilled to the canals during overflows has been estimated by several investigators to be in the range of three to five per cent for sanitary sewage interceptors designed for one and one half to three times the average dry weather flow. However, the first slug of such wastes may be several times the strength of the normal sewage flow.

In 1947, J. E. McKee ( ), reporting on studies for sewage disposal in the Merrimack River Valley Sewerage District in Massachusetts, showed that, although only a small per cent of the annual sanitary sewage flow is lost in storm water overflows, a large percent of the sewage present in the combined sewers during rainstorms is lost during overflows. McKee's studies also showed that with interceptors designed for one and one-half to three times the average dry weather flow, overflows will occur every five or six days on the average during summer months. Thus the receiving stream would be seriously polluted for short but frequent periods during rainstorms; this would greatly restrict the recreational use of the stream.

McKee's study also showed that increasing the capacity of the interceptors for the purpose of reducing the frequency of overflows sufficiently to avoid pollution of recreational waters was generally not economically feasible. Studies reported by C. L. Palmer (3) for Detroit, Mich., E. Riise-Carstensen (4) for Buffalo, N.Y., C. F. Johnson (5)(6) for Washington, D.C., T.R. Camp (7) for Concord, N.H., W. W. Horner (8) for St.Louis, Mo., S. A. Greely and P. E. Langdon (9) for New York City, H. H. Benjes et al.(10) for Kansas City, Mo., and A.L.H. Grameson and R. N. Davidson (11) for Northampton, England, have supported the findings of McKee. However, as Johnson (6) pointed out, where the highest recreational use of a stream is desired, it may be economically practicable to design interceptors for as much as 30 times the average dry weather flow.

The public health problem of pathogens in combined sewage was emphasized by Camp (12) in a report of studies of chlorination of raw sewage for bacteria kills and virus inactivation. British practice in the treatment of combined sewage was reviewed by H. Romer and L. M. Klashman (13).

An analysis of the present condition of the Chicago canal system from Wilmette to the confluence with the Des Plaines River reveals the presence of organic loadings in significant amounts from sources other than known municipal and industrial waste discharges. The loads from known sources are presented in Table IX-1 and average about 200,000 pounds of ultimate BOD per day for the period of study. The unidentified source loads, which are presented in Table IX-2, average about 100,000 pounds of ultimate BOD per day for the same period. It is believed that combined sewer spillage during periods of storm runoff is an important source of the unidentified loads.

GLIRBP has undertaken a study of combined sewer overflows to determine the pollution loads discharged to the streams from selected combined sewers during storms. By extension of the observed data, the total pollution load entering the streams from the sewer system can be estimated, and the major sources of these loads can be located.

Flows have been measured and sampled in two combined sewers, the Roscoe Street sewer on the north side of the city, and the Union Avenue sewer located just south of the Loop area, see Figure VIII-3. However, due to the paucity of data collected at the Union Avenue site, only the Roscoe Street data were used in this analysis.

Study Area

The drainage area of the Roscoe Street sewer is about 8.6 square miles. The City of Chicago follows the practice of providing interconnections between major sewers serving adjacent drainage areas. This provides needed relief drainage for localized storms, together with economy of design. However, it often also results in indistinct drainage boundaries. About 2.4 square miles of the Southwest portion of the Roscoe Street sewer area is interconnected with the Wrightwood Avenue sewer and with the Kostner Avenue sewer. The interconnected area was assumed to be tributary to the Roscoe Street sewer for the purpose of this study. The drainage area slopes from elevation 645 feet above mean sea level (ft. m.s.l.) near the western boundary to elevation 592 ft. m.s.l. at the diversion chamber - an average fall of about 10 feet per mile. The impervious surface is estimated to be 42 per cent of the total area, based on land use data obtained from the Chicago Area Transportation Study, and from land use imperviousness factors from the Division of Sewer Planning, City of Chicago. Land use and per cent imperviousness are shown in Table VIII-7.

Hydraulic Measurements

At the point where dry weather flow is diverted to the Metropolitan Sanitary District interceptor sewer, the Roscoe Street combined sewer is a twin 12' x 12' horse-shoe section, with an invert slope of 0.0005, and a nominal capacity of 1,200 cfs when flowing full. Ports are located about every 150 ft. in the common wall to equalize flow. At the diversion chamber, the invert of the sewer is about 7 feet below river level. Flap gates in the outfall section prevent backflow from the river. The water level in the sewer must rise above the river level before overflow begins, thus providing considerable storage in the sewer system, which prevents overflow during rains of low intensity, and reduces the overflow during larger storms. A sketch of the diversion chamber is presented on Figure VIII-4.

Float type water stage recorders were installed in float wells in manholes located 460 feet and 1930 feet upstream from the diversion chamber. These gages indicate the hydraulic gradient in the sewer, and discharge is determined from computed rating curves.

Diversion to the interceptor is through a 4' x 4' sluice gate which was open half-way during the period of study. This gate is motor-operated, and equipped for automatic operation based on water level in the interceptor. The sewer invert is raised 2 ft. at the downstream side of the diversion chamber, forming a dam to divert dry weather flow.

Float-type water stage recorders were installed upstream and downstream of the sluice gate. Discharge is determined from a computed rating curve for the sluice gate opening. The discharge coefficient for the gate opening was determined from current meter measurements made through the stop-log slot located just upstream from the gate.

Rate of flow to the river was determined as the difference between total flow in the sewer and the diverted flow during the period of overflow. The overflow period was determined by observation of the flap gates and by interpretation of gage height record on the recorder charts. It was found that water levels remained nearly constant during the overflow period so that storage corrections were not required.

Two recording rain gages were installed to supplement the rainfall data from existing rain gages.

Sampling Procedure

In order to man the sampling operation ahead of an expected overflow, an alerting procedure was set up, in which the U. S. Weather Bureau notifies Project supervisory personnel when a rainfall of about 0.1 inch per hour with a total of around 0.5 inch is expected. The supervisor then notifies sampling personnel, laboratory personnel and an engineer from the hydraulics section.

Bulky sampling equipment such as ice chests and sample containers were stored previously in the underground diversion chamber, so that sampling personnel would have a minimum amount of equipment to transport to the site.

Sampling procedure before and during a storm is

Bacterial samples at diversion chamber and on outfall sewer, hourly throughout.

BOD samples at both locations, hourly before water level starts to rise, every 15 minutes during the rise and overflow periods, and every 30 minutes after overflow stops until the water level recedes to low stage.

DO samples on the outfall sewer only, with same frequency as for BOD samples.

During periods of runoff and overflow when samples were being taken, an engineer from the Project was on hand to make sure that gages were functioning properly, and to observe flow conditions.

Background sampling of dry-weather flow was carried on during October, 1961.

Considerable difficulty was experienced in obtaining adequate samples of storm flow. The main factor was the extremely difficult problem of making accurate quantitative precipitation forecasts for relatively small geographical areas. It was found that an average rainfall intensity as low as 0.04 in./hr. would produce an overflow under certain conditions. The lag time between beginning of rainfall and overflow was usually about two hours, so that sampling should have been started within about one hour after rainfall began. This proved to be very hard to accomplish when rainfall occurred after regular working hours, due to time required to recruit sampling personnel, travel time, etc. When rainfall occurred without advance notice during regular working hours, sampling personnel were often in the field on other assigned duties and not readily available. In all, adequate data were obtained from only five storms.

Dry Weather Flow

Average dry weather flows were determined from the sluice gate rating curve for periods considered to be representative of the entire period of gage record. Average flows for November, April, June, and August are shown on Figure VIII-5. The estimated annual average dry weather flow is 45 cfs.

Samples of dry weather flow in Roscoe Street sewer were collected on 23 days during the period September 27 to November 2, 1961. Average concentrations reported in the laboratory analyses, and the estimated annual average dry weather load, based on an average flow of 45 cfs, are shown on Table VIII- .

Storm Flow

During the period of gage record (Sept.-Dec. 1961 and March-Nov. 1962) there were 36 storms which caused overflow. The average duration of overflow was 3.9 hours. Monthly distribution is shown on Table VIII-9. Rainfall and runoff data for 34 of these storms are summarized on Table VIII-10. Discharge hydrographs and hourly rainfall for the storm of November 15-16, 1961, are shown on Figure VIII-6.

Pollution Load

Samples obtained during overflow periods were composited in the laboratory prior to analysis. The results of the laboratory analyses are shown on Tables VIII-11 to VIII-15. It was expected that there would be a relationship between the strength of the combined sewage and the time after beginning of rainfall. The 5-day BOD concentrations were found to vary with time as shown on Figure VIII-7. In order to extend these data, calculation of the total BOD load to the system is shown on Table VIII-16 and is explained below.

The volume of overflow in each 30-minute period, after start of overflow, was computed for the 31 storms which occurred during the months October-December 1961, and April-September 1962. October and November 1962, were omitted from this computation to avoid duplication of months. The corresponding BOD concentration for each 30-minute period was taken from the curve on Figure VIII-7, and the total BOD load discharged to the stream during the 31 storms was computed to be 278,300 lb. The duration of overflow was 126.7 hours in nine months of total time. This would be an average daily load of 1,010 lb. for the 9-month period. It was considered that the annual average daily load would not differ appreciably from the 9-month average.

It was assumed that the frequency, duration, and volume per unit area of the overflow from the Roscoe Street sewer would be representative of the overflows to be expected from all sewered areas tributary to the Sanitary Canal. This is recognized as an oversimplification of the complex relationships between rainfall intensity, time of concentration, imperviousness, storage in the sewers below river level, etc. However, on the basis of the information available at this time, the assumption is considered reasonable. A study of an adequate number of sewers to define the overflow characteristics of the entire tributary area is beyond the scope of the GLIRB Project.

It was further assumed that, in the tributary area of each main treatment plant, the ratio of the total overflow BOD load to the Roscoe Street overflow BOD load would be equal to the ratio of the total BOD load received at the plant to the total BOD load diverted from the Roscoe Street sewer into the MSD interceptor.

The total BOD loads received at the treatment plants are not available for 1962, when most of the Roscoe Street data were collected, therefore average loads based on records for 1957 through 1961 were used. The BOD load to the Stickney Plant was adjusted to delete that part of the load from suburban areas where the sewers overflow to the Des Plaines River.

The total BOD load diverted from the Roscoe Street sewer to the MSD interceptor was not determined, since data for storms not producing overflows have not been analyzed at this time. Therefore, the dry weather BOD load was used for this purpose.

The 5-day BOD overflow load in each treatment plant area was computed separately:

North Side: $\frac{178{,}400\ (1{,}010)}{25{,}200} = 7{,}100$ lb./day

Stickney: $\frac{887{,}300\ (1{,}010)}{25{,}200} = 35{,}500$ lb./day

Calumet: $\frac{106{,}500\ (1{,}010)}{25{,}200} = 4{,}300$ lb./day

The total 5-day BOD overflow load to the canal system was 46,900 lb./day.

Precipitation during the nine-month period of gage record was below normal in all months except October 1961, and July 1962. The nine-month total was about 80 percent of normal for Midway Airport gage. Precipitation for the 12-month period October 1961 through September 1962, was about 85 percent of normal.

Sludge Deposits

Investigation of sludge deposits in the Upper Illinois River System was instituted during August 1961. The investigation was made to determine the distribution of sludge on the stream bottom. It included the entire North Shore Channel from mile point NS 340.7 to its junction with the Chicago River at mile point 325.5, the Chicago River and South Branch of the Chicago River, and the Sanitary and Ship Canal down to the junction with the Calumet Sag Channel at mile point SS 303.5. In all, 37.2 miles of stream were surveyed using an indicating type of depth probe. This probe operates with ultrasonic sound waves. It emits the sound from a transducer located in the bottom of the survey boat - which is directed downward through the water in a narrow beam. When this beam strikes bottom, or any other material of heavier density than water, it will be reflected; a portion of the beam returns to the transducer in the boat. The elapsed time, while the sound wave travels to the point of reflection and returns, is a function of the depth of water at that point. The instrument used was the Columbian Aqua-Probe Depth Finder, Model CB 303.

The readings, plotted in Figure VIII-8, have been corrected for the water level elevation at the time of the study and for the depth of setting of the transducer in the boat hull. The depth of the sludge deposits shown in Figure VIII-8, was an average depth taken at the center line of the stream; it did not show the conditions on either side of the track of the boat as it moved down the center of the stream.

The relationship of the sludge deposits to the known stream profile varied from zero at Wilmette to seven feet at mile point SS 317.5 just upstream from the Cicero Avenue Bridge on the Sanitary and Ship Canal. Some peaking was noticed below the various outfalls and treatment plants. The sludge line dropped 2½ to 3 feet at the point where the Canal narrows below the Wentworth Bridge at mile point SS 308.0.

The method of measurement used is accurate, within limitations, and for this application may indicate a thin layer of sludge or blanket of flocculent material suspended in the stream. The height of the sludge shown in the Figure does not indicate what the physical condition of the sludge was at any point, but does show that a blanket of different density existed from that point to the bottom of the stream.

Heavy accumulations of sludge existed in the North Shore Channel below the Roscoe Street diversion sewer, the Addison Street pumping station, and the Northside Sewage Treatment Plant. Some sludge concentrations mixed with grit existed in the turning basin below the North Avenue Bridge. In the Chicago River, South Branch of the Chicago River and the Sanitary and Ship Canal, heavy sludge concentrations occurred from a point north of the Cicero Avenue Bridge to about mile point SS 307.9 Below mile point SS 307.9 the velocity of the Sanitary and Ship Canal increases and some scour occurs. Sludge boils and gaseous emission from the sludge below the treatment plants dotted the surface of the water like rain at these points. Some sludge was turned up by towboats in this area. These tows exert a powerful influence on the bottom of the stream - at times strong enough to bring oil - and water-soaked 12x12 inch timbers 12 to 15 feet long to the surface from the bottom. These wood timbers and debris which boil to the surface present a hazard to small boats; they also serve to illustrate the powerful suspension and mixing forces exerted by passing towboats.

The results of the sludge deposit survey confirm the existence of large and extensive sludge deposits which would be responsible for a significant portion of the demand on the oxygen assets of the stream.

Continuous Dissolved Oxygen Recording

Scope of Investigations

One of the special investigations undertaken by the Project was a study of surface water dissolved oxygen concentrations using continuous dissolved oxygen recorders.

The instruments were installed at Wilmette Inlet on the North Shore Channel (river mile 340.7), above the dam at Lockport on the Ship and Sanitary Canal (river mile 293.1), and above the dam at Peoria on the Lower Illinois River.

Each instrument was serviced at least every eight days. Results from the recorder charts were spot checked with the modified Winkler dissolved oxygen test. The averages of maximum and minimum values observed at three sampling stations are given in the following table:

	Wilmette		Lockport		Peoria	
	Max	Min	Max	Min	Max	Min
Time of Occurrence of Maximum or Minimum	4:30 PM	8:00 AM	6:00 PM	10:00 AM	6:00 PM	8:00 AM
Temperature of Water (°C)	16.6	15.2	26.1	25.6	18.2	16.0
% Saturation of Dissolved Oxygen	100	95	5	0.7	68	59
Concentration of Dissolved Oxygen (mg/l)	9.8	9.5	0.4	0.1	6.4	5.8
Period of Operation	10/5/62 to 10/15/62 10 days		8/11/62 to 10/16/62 44 days		9/6/62 to 10/18/62 29 days	

On a significant number of occasions, the recorder at Lockport registered a dissolved oxygen reading of zero, for periods of 12 to 18 hours at a time. These continuously recorded observations comfirm the findings of the earlier studies at these sampling locations.

Description of Dissolved Oxygen Analyzers

The Hays Dissolved Oxygen Meter was used in the investigation. This instrument consists of three basic units; the contact sampler, the oxygen analyzer, and a recorder.

Contact Sampler

The sample water is continuously pumped through a pressure regulator into an aspirator. Here the water is thoroughly mixed with the oxygen bearing gas returning from the analyzer. Thorough mixing of the confined gas and the influent sample water brings the mixture to equilibrium. At equilibrium the partial pressure of oxygen above the water surface is directly proportional to the amount of oxygen in the water. Measurement of the partial pressure of the oxygen gas, therefore, is a quantitative measure of the amount of dissolved oxygen in the sample water.

From the aspirator, the gas-water mixture is forced into the water-gas separator, where the gas is centrifugally separated from the water. At this point, the water is discharged from the separator while the gas passes to the analyzer.

Analyzer

The paramagnetic property of oxygen is the principle utilized by the Hays Analyzer. Paramagnetism is defined as the property of becoming magnetized when placed in a magnetic field, in the direction of the field, This phenomenon is unique among only a few gases and peculiar only to oxygen in gases common to the atmosphere.

When an oxygen-bearing gas is introduced into the analyzer, it is attracted into a magnetic field surrounding one of two similar heated resistance elements. The specially constructed wire-wound platinum resistors are suspended in each of the two chambers within an analyzer cell block. These resistors form one leg of a Wheatstone bridge network and are heated by the cell block bridge supply circuit. Both resistors are exposed to, and cooled by, the sample gas.

As a result of being heated, the oxygen bearing gas loses its magnetic properties and is immediately replaced by cooler, more magnetic gas drawn into the field. Since the magnetic field surrounds only one chamber, there is a difference in cooling effect between the two resistors. The temperature difference results in an electrical resistance difference between the resistors, which in turn causes a voltage difference to appear across the output of the bridge circuit. Moreover, this voltage difference is directly proportional to the amount of oxygen present in the sample gas. From the analyzer the sample gas returns to the aspirator where it is mixed with fresh sample water to complete the gas sample flow loop.

Recorder

The voltage difference across the output of the bridge circuit, as a result of the temperature difference in the cell block resistors, is applied to the amplifier circuit. The amplifier amplifies this voltage, adjusts the phase, and causes a pen drive motor to operate. Readings are presented on circular charts as the dissolved oxygen content of the sample water or in percent of saturation, as desired.

REFERENCES

1. 26 Federal Register, 6737, July 27, 1961; amendments Federal Document 62-2191, March 6, 1962.

2. McKee, J. E. Loss of Sanitary Sewage through Storm Water Overflows. Journal of the Boston Society of Civil Engineers, 34, 2: 55 (April 1947).

3. Palmer, C. L. The Pollutional Effects of Storm-Water Overflows from Combined Sewers. Sewage and Industrial Wastes, 22, 2: 154 (February 1950).

4. Riis-Carstensen, Erik Improving the Efficiency of Existing Interceptors. Sewage and Industrial Wastes, 27, 10: 1115 (October 1955).

5. Johnson, C. F. Nation's Capital Enlarges Its Sewerage System. Civil Engineering, 28 2: 56 (June 1958).

6. Johnson, C. F. Equipment, Methods, and Results from Washington, D. C., Combined Sewer Overflow Studies. Journal WPCF, 33, 7 721 (July 1961).

7. Camp, T. R. Overflows of Sanitary Sewage from Combined Sewerage Systems. Sewage and Industrial Wastes, 31, 4: 381 (April 1959).

8. Shifrin, W. G., and Horner, W. W. Effectiveness of the Interception of Sewage - Storm Water Mixtures. Water Pollution Control Federation, Philadelphia Convention, (October 1960.)

9. Greeley, S. A., and Langdon, P. E. Storm Water and Combined Sewage Overflows. A.S.C.E. Journal of Sanitary Engineering Division, 87, SA 1: 57 (January 1961).

10. Benjes, H. H., Haney, P. D., Schmidt, O. J., and Yarabeck, R. R. Storm-Water Overflows from Combined Sewers. Journal WPCF, 33, 12: 1252 (December 1961).

11. Gameson, A. L. H., and Davidson, R. N. Storm-Water Investigations at Northampton. The Institute of Sewage Purification, Annual Conference, Llandudno, (June 1962.)

12. Camp, T. R. Chlorination of Mixed Sewage and Storm Water. A.S.C.E. Journal of Sanitary Engineering Division, 87, SA 1, 1 (January 1961).

13. Romer, H., and Klashman, L. M. The Influence of Combined Sewers on Pollution Control. Public Works, (October 1961.)

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IX THE IMPACT OF WASTE LOADS ON THE STREAM

Introduction

This chapter will be concerned with the dynamics of self-purification of the Upper Illinois River System as it receives and attempts to assimilate the complex pattern of organic waste loads that are imposed upon it. The primary purpose is to evaluate the present degree of organic pollution and the relative importance of the several causes or kinds of pollution. As a part of the analysis, the self-purification capacity of the stream system is estimated, and will serve later as a guide in predicting the effects of corrective measures.

In order to evaluate the self-purification capacity, thorough analysis of existing conditions is necessary. Based upon initial evaluations of the existing waste loads, river flows, organic sludge demands, tributary flow, atmospheric reaeration, and other factors, calculations of the self-purification capacity and expected dissolved oxygen levels (DO) in the stream are tested against dissolved oxygen profiles actually observed. Once agreement between calculated and observed dissolved oxygen concentrations is obtained, it is possible to predict with confidence.

It is important to realize that this procedure is a science of estimating, and is not exact in the sense that physics and chemistry are exact sciences. We are measuring the chemical results (DO) of a complex and dynamic biochemical process that is highly sensitive to relatively slight environmental changes. The existing body of knowledge on this subject is not complete, especially insofar as modification of waste loads or the stream environment may, to a limited degree, alter one or another of our basic parameters. For these reasons, there will always be a range of uncertainty in DO predictions, and the degree of uncertainty will, to a large extent, depend upon the complexity of the river system under study.

Stream Self-Purification

In essence, the organic pollution added to a flowing stream is attacked as food by the stream bacteria. As a part of this process the bacteria require oxygen, and utilize the dissolved oxygen of the stream. In turn, the stream's oxygen resources are steadily replenished, primarily by a higher quality tributary inflow and by atmospheric reaeration. Thus, in any flowing stream, there is a continuous action and reaction in a balancing process between the demands for oxygen and the available oxygen resources. The extent to which the oxygen resources are depleted is the measure of whether the stream remains in good condition or becomes seriously degraded by an excess of organic pollution.

Thus, we speak in terms of stream assets (available dissolved oxygen and the means by which it is replenished) and liabilities (demands for oxygen and the modes by which such demands are exerted). Quantitative analysis of stream self-purification capacity consists of accounting for all of the assets and liabilities involved and conducting a balance of the DO and the oxygen demands.

Stream Assets

The two primary sources of dissolved oxygen are tributary flow and atmospheric reaeration. Existing flow in the main stream and that brought in by tributary streams carries DO with it, and this is usually a relatively large source of oxygen in pounds per day. It is well to note here that additional tributary flow ("dilution"), over and above the usually available flow, improves the oxygen balance in essentially one major respect - it carries an added oxygen resource available to meet oxygen demands.

In contrast to deoxygenation, which is a biochemical process involving the intervention of living things, atmospheric reaeration is a purely physical process. When water is in contact with the atmosphere, the concentration of dissolved oxygen in the water tends toward a "saturation" level at which the partial pressures of oxygen in the two media are equal. When the DO of the water is lower than this possible saturation concentration, the partial pressure of oxygen in the water is lower than that in the air. This difference of pressures is the driving force by which the water takes up oxygen from the air in the ever-present attempt to equalize these pressures. The greater the degree of oxygen depletion in the water, the greater the partial pressure difference, or driving force, and, hence, the faster the reaeration process. Reaeration of still water in a glass is quite slow, whereas in a flowing stream, turbulence and mixing result in a much faster process because the water is much more frequently brought into direct contact with the air. Streams can become "supersaturated" with DO due to photosynthesis - when this happens deaeration takes place, as the direction of the driving force is reversed.

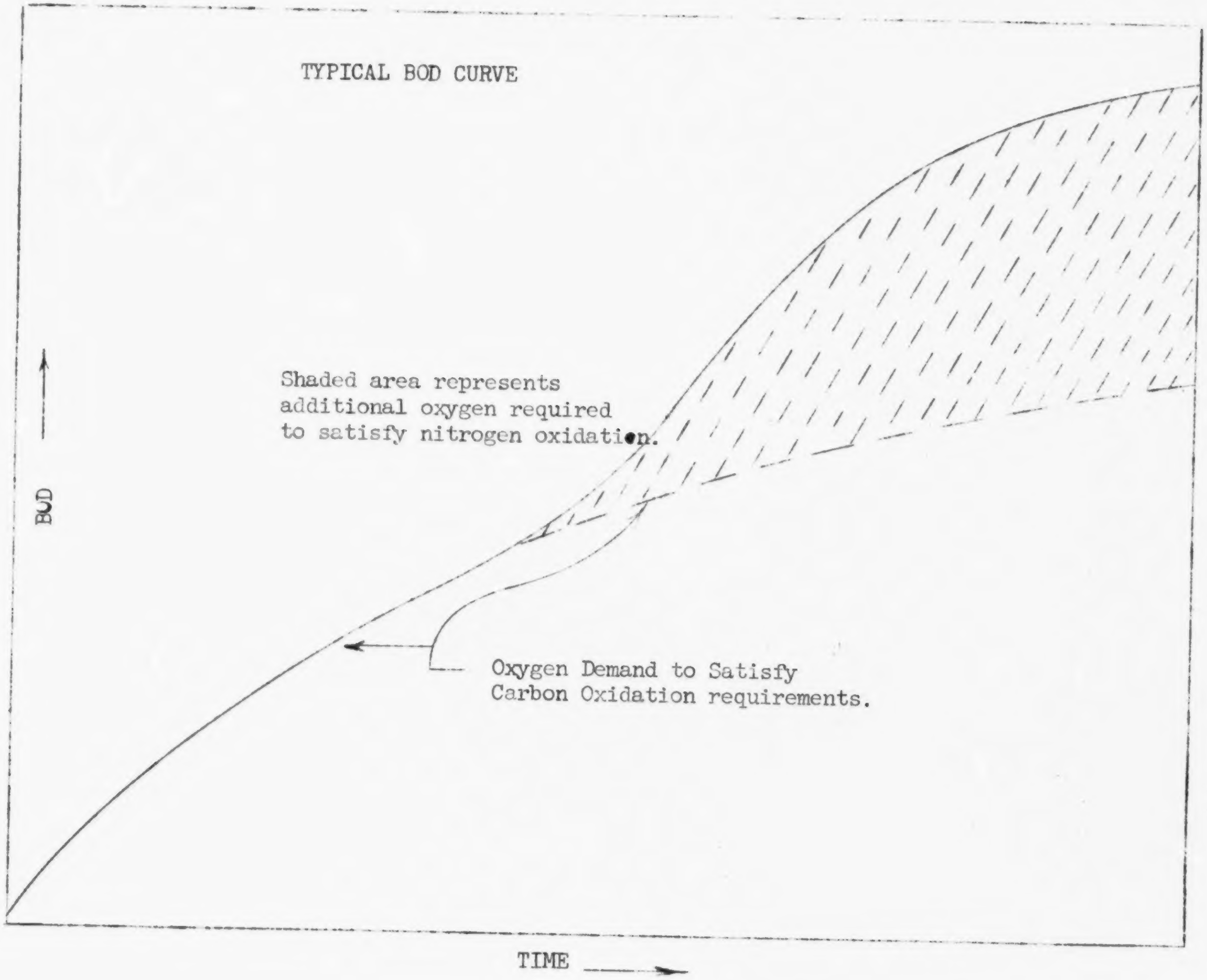
Certain other events in the stream can be looked upon as assets to some degree. During the daylight hours, green algae, if present in the stream, produce oxygen by photosynthesis. However, this is not an unmixed blessing, as the same algae, by respiration, demand corresponding quantities of oxygen, causing further oxygen depletion in the dark hours when photosynthesis cannot proceed. Also, when the DO becomes completely exhausted, the stream becomes anaerobic, and gases such as methane and hydrogen sulfide may be evolved and lost to the atmosphere with accompanying odor nuisance. A portion of the liabilities, or oxygen demands are wiped out by this process, and improvement of downstream conditions is somewhat hastened.

Stream Liabilities

The introduction of organic wastes brings about depletion of the DO of a stream, through the activities of bacteria. The oxygen-depleting ability of a waste is referred to as its BOD (Biochemical Oxygen Demand). It should be noted here that the BOD is a measure only of the oxygen-depleting ability of a waste under specific test conditions, and it is not a measure, for instance, of total organic content.

The satisfaction of pollution loads in a stream, or deoxygenation, is a time- and temperature-dependent reaction that usually takes place in two stages, a so-called first stage which involves carbon oxidation, and a second stage, referred to as nitrification, in which nitrogen compounds are oxidized (see schematic diagram). The "ultimate first-stage demand" is the demand that would be measured if carbon oxidation were carried to completion (broken line in schematic diagram). It is a theoretical figure, not measured, because nitrification is superimposed and because of the long periods of observation that would be involved (twenty days, more or less). Usual procedure is to observe the 5-day demand and convert it to the ultimate first-stage demand on the basis of estimates or tests of the actual rate and course of the reaction. If it proves necessary or desirable, the second-stage demands may be evaluated by successive analysis of the two stages, first evaluating the course of carbon oxidation, then deducting the day-by-day first-stage demands from the observed data, the differences being the day-by-day second-stage demands.

The rate at which the BOD is exerted is substantially affected by the temperature of the stream, bacterial activity (and consequently the BOD reaction rate) being greater at high temperatures and reduced as the temperature decreases. In addition, at higher temperatures water cannot hold as much oxygen as at low temperatures--the DO saturation concentration decreases as temperature rises. Thus, increased water temperatures, which may be due to seasonal variation or to cooling water use, result in reduced dissolved oxygen resources and reduced capacity of the stream to assimilate pollution.


TYPICAL BOD CURVE
Shaded area represents additional oxygen required to satisfy nitrogen oxidation.
Oxygen Demand to Satisfy Carbon Oxidation requirements.
BOD
TIME

One other type of stream liability is of importance in the studies at hand, namely, the occurrence of organic sludge deposits on the river bed. Such deposits, consisting of settleable organic waste solids, usually form in reaches of low stream velocity where they can settle most readily. As sedimentation of suspended organic material continues the deposit becomes deeper, its organic content accumulates, and its oxygen-demanding capacity becomes greater. Eventually, if undisturbed accumulation continues, an equilibrium is reached whereby the amount of daily oxygen demand from such a deposit is equal to the total amount of BOD deposited daily.

Except at the very top, sludge deposits undergo anaerobic decomposition as a result of bacterial attack. This is a slow process relative to the usual aerobic decomposition of flowing dissolved loads. The soluble end products of the process pass upwards to the sludge-water interface, and into the flowing water, where they undergo direct chemical oxidation at a rapid rate. In this way they usually create a highly localized and immediate demand for oxygen from the flowing water. This type of demand, at times amounting to nearly a point-load, is especially damaging, as little or no time is available for atmospheric reaeration to counter or keep up. The time scale of the usual oxygen sag curve is thus compressed, critical DO's usually occur at the deposit area, and the DO's are lower than would have occurred due to normal deoxygenation in the flowing water.

Such sludge beds are also occasionally scoured by higher stream velocities. In this event, the transported solids undergo the usual, more rapid aerobic degradation. If the prior accumulation period has been long, this can result in the sudden addition of a substantial flowing load. Although this type of situation usually occurs in conjunction with flood flows (and much additional dilution) the sludge bed can be disturbed and scoured by other means, such as barge traffic, at low flows when no additional dilution is available.

The natural self-purification capacity of any specific stream is strictly limited in terms of the available oxygen resources. If the organic pollution loads added are too great the available oxygen resources can be exhausted, with resulting nuisance conditions, much in the same way that a bank account can be overdrawn.

Mathematics of Self-Purification

Well recognized mathematical models are available to describe the basic processes involved in self-purification, and although there is occasional question as to their theoretical perfection, they are quite adequate for practical purposes. They include equations for deoxygenation, reaeration, and the oxygen balance, as given earlier by Streeter and Phelps,* and are outlined briefly below.

As given by these authors:

"The rate of the biochemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms of oxidizability."

In mathematical terms this states that

$$\frac{dL}{dt} = -K_1 L \qquad (1)$$

in which L is the amount of ultimate first-stage demand remaining unexerted after t days, and K_1 is a reaction velocity constant that describes the rate at which the demand is exerted.

Stated in another way, Equation (1) indicates that the more BOD that is present, the faster the oxygen will be used up. Equation (1) has as its solution:

$$L = L_a e^{-K_1 t} \qquad (2)$$

in which L_a is the ultimate first-stage demand, or the potential demand at time zero. Thus, a plot of L versus time would yield a curve that descends from an initial value, L_a, and approaches zero after a long time. This curve would be a mirror image of the first-stage BOD curve shown in the preceding schematic diagram. If this descending curve is plotted instead as the logarithm of L versus time, a descending straight line whose slope is k_1 is obtained (k_1 is the BOD velocity constant converted to the base 10, for convenience in computations. Its value is $0.434\ K_1$).

The difference between any two points on this curve represents the amount of oxygen demanded, or used, during that period. For instance, if the value of L at 5 days is deducted from the 2-day value, the difference is the amount of BOD exerted, and also the amount of oxygen used, during this 3-day period. This is the basis for the graphical method of integrating pollution loads that has been used in the computations described later.

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* Streeter, H. W., and Phelps, E. B. A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration. Public Health Bulletin No. 146. (1925)

The stream reaeration process is formulated according to the principle that the rate at which oxygen is dissolved into the flowing water is directly proportional to the oxygen deficit below saturation; in other terms, the oxygen deficit decreases at a rate proportional to its own magnitude.

Mathematically

$$\frac{dD}{dt} = -K_2D \qquad (3)$$

where D is the oxygen deficit below saturation at t days, and K_2 is the velocity constant that describes the rate at which reaeration is taking place.

Equation (3) is solved by the expression

$$D = D_ae^{-K_2t} \qquad (4)$$

where D_a is the initial oxygen deficit below saturation, or the deficit at time zero. Thus, Equation (4) indicates that as time passes the oxygen deficit will approach zero, or the dissolved oxygen will approach its saturation value, due to reaeration.

In a flowing stream, K_2 is a function of the depth and velocity of flow, or the degree of turbulence and mixing, and the rate at which oxygen can diffuse from the air into the water. Several equations for the computation of K_2 have been proposed over a period of years. One of the more recent, and the one that has been used in the computations for the Illinois River System, is the O'Connor-Dobbins* model

$$K_2 = \frac{(DV)^{1/2}}{H^{3/2}} \qquad (5)$$

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* O'Connor, D. J., and Dobbins, W. E. The Mechanics of Reaeration in Natural Streams. Trans. ASCE, 123, 641-684. (1958)

in which D is a diffusion coefficient, V is the mean velocity of flow, and H is the mean depth.

In any real stream pollution situation the processes of deoxygenation and reaeration go on simultaneously, and it is not possible to observe their separate courses. Instead, the two processes can be combined mathematically to yield the well known oxygen sag equation of Streeter and Phelps. To do this, Equations (1) and (3) are combined to yield

$$\frac{dD}{dt} = K_1L - K_2D \qquad (6)$$

which indicates that deoxygenation (K_1L) increases the oxygen deficit, while the counter process, reaeration, decreases the deficit. Equation (6) has as its solution

$$D = \frac{K_1L_a}{(K_2-K_1)}\left(e^{-K_1t} - e^{-K_2t}\right) + D_ae^{-K_2t} \qquad (7)$$

which is the widely used oxygen sag equation.

There is no method available by which K_2 can be obtained directly in the usual stream pollution situation, because of the simultaneous occurrence of deoxygenation. The sag equation represents an idealized case involving only one pollution load, and the absence of additional factors such as sludge deposits and photosynthesis. Many pollution cases approach this degree of simplicity, however, and in such cases the traditional practice for indirectly determining K_2 has been to measure all of the other factors in Equation (7) and then compute the resulting value of K_2. Such an approach is impossible in the highly complex Upper Illinois River pollution situation. Instead, therefore, the necessary numerical estimates of K_2 must be obtained from an independent equation such as Equation (5).

The Oxygen Balance

In complex situations such as that under study here, involving many pollution loads, sludge demands, and the like, the oxygen balance technique offers the best approach to analysis. In essence, this consists of making independent estimates of as many of the assets and liabilities as possible, and combining these estimates in a balance sheet to test them against the observed DO profiles in the stream. A running balance of oxygen income and loss is kept, in much the same fashion as a financial balance is developed over a period of time.

Consider a short reach of stream whose upstream end is Station A, and whose downstream end is Station B. Then the total available assets in the reach AB are the DO initially available at A, and the oxygen income in the reach AB from reaeration and from additional tributary flow:

Total Assets, AB = DO at A + DO income from reaeration + DO income from tributary flow.

The total liabilities, or oxygen losses, in the reach AB include the oxygen used in satisfying the flowing organic loads, and the oxygen lost as a result of sludge demands:

Total Liabilities, AB = DO loss due to flowing BOD + DO loss due to sludge demands.

The net DO remaining at B is just the amount obtained by subtracting the total liabilities from the total assets:

DO at B = Total Assets - Total Liabilities.

For these studies of the Upper Illinois River System, 20 sampling stations have been used, resulting in an average reach, AB, two and one-half miles in length. The assets for each reach have been estimated by the methods indicated earlier: the available DO at the upper end has been obtained by measurement, the DO income from reaeration has been estimated by the use of Equations (3) and (5), and any DO income from added tributary flow has been obtained by field measurements. Thus, the estimates of total available assets for each reach do not involve great uncertainty, and are correct within reasonably narrow limits of possible error.

Estimating the total liabilities for each reach has not been so straightforward, as a number of factors complicate and conceal the true pollution load situation. These include the existence of illicit waste outfalls that release unknown quantities of BOD, the erratic and largely unknown loads delivered to the System from combined waste outfalls during storms, and the resuspension, redistribution and resettling of organic sludges by barge traffic. To attempt to measure all of these effects in the field is out of the question because of technical and time limitations, to say nothing of reasonable costs. Thus, a BOD balance system has been devised and used to permit adequate estimates of the above factors. This will be described in detail in the following sections.

The Illinois River System

The Illinois River System is over 300 miles long, the main stem extending from Lake Michigan at Chicago to the Mississippi River at Grafton, Illinois. In this report, the river mileage index system from Grafton is used. Station 1, at the Wilmette entrance to the North Shore channel, is at mileage NS 340.7. Station 22 is at the upstream side of the Lockport Dam at mileage SS 291.1. The Dresden Dam station, No. 27, is at mileage index IR 271.5. The farthest downstream station that was regularly sampled was at the Hardin Highway Bridge at mileage IR 21.7.

Generally, velocities in the stream are slow--ranging from 0.1 to 1.4 feet per second at normal flows. The flow time from Station 1 to Grafton is in the range of 20 days. This low velocity is due to the flat terrain and the large cross-sectional areas created by the navigation pools.

Because of its length, the practical problem of adequate sampling was solved by sampling over monthly intervals, and by sampling the system in two parts. For purposes of analysis reported in this chapter, the Upper Illinois River System is considered to be the length from Station 1 to Station 22, or Wilmette down to Lockport Dam, mileage 340.7 to 291.1. The Lower River is considered to be the reach from Dresden Dam, mile 271.5, to Grafton at mile zero. These two parts were sampled and studied as units, and will be discussed as these parts.

The Upper Illinois River System, as previously described in Chapter I, is a complex and artificially controlled canal system. From Lockport downstream to the mouth of the Illinois River, the main stem is a succession of slack-water pools formed by the navigation dams that make it a part of the inland waterway system. Including Lockport, there are seven locks and dams on the system, with lifts ranging from 10 to 40 feet. The waterway was designed and is maintained to provide for vessels having a maximum draft of 9 feet. Heavy siltation has occurred in the pools, with the result that a typical pool consists of shallow overbank areas on each side and a channel portion which is kept clear by a combination of river current, barge traffic, and dredging.

Generally, the Upper System channels, in the Chicago area, can make only limited recovery by natural purification from the impact of discharged organic waste loads. This is due to the combination of slow velocities, low diluting flows, repeated heavy pollution loads, and the low available dissolved oxygen.

The Lower Illinois River is generally in the recovery stage of self-purification due to greater dilution, higher velocity, lower turbidity, and the much smaller number and magnitude of pollution loads added in the downstream reaches.

It is known that there are approximately 200 combined sanitary-storm sewer outfalls that overflow directly to the river during storms, numerous industrial waste outfalls, treatment plant discharges, and some illicit waste outfalls in the main channel of the Upper Illinois River System. During times of storm spillage, suspended, dissolved, and settleable wastes are scoured into the Upper Illinois River System. In the River System the sludges may be raised, resuspended and settled again by barge traffic. All of these factors, many of which are known and some of which are unknown, complicate the natural self-purification picture of the Illinois River System.

Field Studies

The Upper Illinois River System was sampled during April-May 1961, June 1961, July 1961, August 1961, and January 1962. The Lower Illinois River System was sampled during November-December 1961, March-April 1962, and July-August 1962. Each of these study periods was approximately one month in time. Complete BOD-DO balances have been computed for the first five study periods on the Upper River. The summaries are in Tables IX-4 through 13.

In the Upper System mainstem there are 20 sampling stations, with an average reach between stations of two and one-half miles. Samples were collected at each sampling station 15 to 25 times during each sampling study period of approximately one month. They were collected at different times of the day and on different days of the week. The results were averaged for each station to give a daily average for the study period. These averages are used in balance computations.

A number of river samples were analyzed to determine the deoxygenation rate constant, k_1. These results are given at a later point.

Existing Loads

The Illinois River System receives waste loads from communities, industries and the storm water runoff from the watershed. The community and industrial wastes are partially treated wastes of a wide variety. The estimated sewered population equivalent discharged into the Upper River System totals nearly 800,000. The estimated discharge into the Lower River is nearly 700,000 P.E. The 800,000 P.E. comes into the Upper River in a length of about 50 miles, while the 700,000 P.E. comes into the Lower River in a length of nearly 200 miles.

The storm spillage load into the Upper River is sewage plus storm runoff. This load is in the range of 260,000 P.E.

The known industrial waste load estimated to be going into the Upper River is 500,000 P.E. The known industrial waste load estimated to be going into the Lower River is 320,000 P.E.

The grand total of these estimates comes to an imposed load on the mainstem and tributaries of about 2,500,000 P.E. This is equivalent to about 400,000 pounds per day of 5-day BOD, or 625,000 pounds per day of ultimate first-stage BOD.

The unknown pollution loads that could not otherwise be evaluated were estimated as "mid-station loads" by the balance procedures outlined later. Quantitative estimates of the sludge oxygen demands for each reach are also outlined in the examples of DO-BOD balances.

Velocity Constants, K_1 and K_2

In the Upper River System, 31 samples were taken for long-term BOD determinations to permit evaluation of the BOD rate constant, k_1. The rate constants were calculated by the Thomas-Slope technique. All 20 of the Upper River sampling stations were represented in this study. The observed values of k_1 ranged from 0.06 to 0.25 per day, depending upon a variety of factors. However, the data (see Table IX-16) demonstrated a definite central tendency toward a single rate constant of 0.139 per day. A statistical analysis of variance of the observed values indicated that the means for the several station ranges were uniform, confirming that the single value of 0.139 would be an adequate representation of k_1 for the whole Upper River. Accordingly, the value $k_1 = 0.139$ per day was used in the subsequent computations.

As noted earlier, direct observation of k_2, the reaeration rate constant, was not possible in the complex Upper River System. Limited laboratory experiments on the rate of oxygen uptake from the atmosphere by deoxygenated river water were undertaken, but have not yielded additional significant data. Hence, the O'Connor-Dobbins equation given earlier was used to obtain estimates of this rate constant.

BOD Balances: Integration of Loads

As indicated earlier, the computation of stream oxygen demands forms the basis for the subsequent DO balances, and involves considerably greater chance for error because of storm overflows from the combined sewers, illicit and unknown loads, and organic sludge deposits.

Accordingly, the first phase of the analysis involves accounting for the known pollution loads and their degradation as they pass downriver, and developing rational estimates of the other, unknown loads. These computations are carried out in the detailed integration, or summation, of pollution loads. The entire computation is given for the April-May, June, July, Aug., and Jan. survey periods in Tables IX-4, 6, 8, 10,& 12,respectively, and in Figures IX-1, 3, and 5, respectively, for the April-May, July, and August periods. A brief discussion will serve to illustrate the use of the Tables and Figures, and to show the mode of computation as it has been devised to minimize error.

Referring to Figure IX-1 and Table IX-4, recall that the curve describing the process of satisfaction of flowing organic loads is a straight line on semi-logarithmic scales, and that the slope of the line is just k_1, the BOD rate constant, according to Equation (2) given earlier. Also, as noted earlier, it has been determined that a single k_1 of 0.139/day is adequate to describe the BOD process in the Upper Illinois River System.

At Station 1 the field surveys indicated a flowing BOD load of 27,960 lb./day, and at Station 2 a flowing load of 27,270 lb./day was found. These points are plotted in Figure IX-1, at the far left. The computation procedure now involves drawing two lines between Stations 1 and 2, both at the slope $k_1 = 0.139$/day; one of the lines passes through the value 27,960 at Station 1, the other through the value 27,270 at Station 2. Thus, the two lines are parallel, but, as seen in Figure IX-1, they do not meet. In this example, the mid-point vertical distance between them involves 240 lb./day of flowing BOD, and the vertical line moves upward, proceeding from Station 1 to 2. In this manner, the computations indicate that an additional BOD load is added somewhere between Stations 1 and 2 in the amount of 240 lb./day. For want of information to the contrary, this estimated load is located at a point midway between the two stations, as a best guess that does not involve major error. This computation has also indicated that 1,000 lb./day of the flowing load has been exerted between Stations 1 and 2, or 1,000 lb./day of DO has been used up.

This is the manner in which all of the estimated "mid-station loads" have been found. In this particular example, the 240 lb./day is a negligibly small load. It may be real, or it may be the product of small error in the basic data used. For instance, in this stretch of stream, and at the particular time of survey, the value of k_1 may have been slightly lower than the average value of 0.139/day that was used. Alternatively, the true average BOD at Station 1 or 2 may have been slightly different than the observed average. It is well to bear in mind throughout these computations that they are estimates, rather than being perfect. We are seeking major mid-station changes, rather than slight differences. In order to do this effectively, however, it is necessary to adopt a single system of computation that is of manageable proportions.

Proceeding downstream, consider the reach between Stations 2 and 3, during April-May 1961. (See Table IX-4 and Figure IX-1). At the upstream end, Station 2, we have a flowing load of 27,270 lb./day. At Station 3, downstream, a flowing load of 30,170 lb./day has been observed. There are no known pollution loads added to the river in this reach, but the data are clear in this case and show that significant, nonnegligible load is being added between Stations 2 and 3. By the process outlined above, this mid-station load is estimated at 3,480 lb./day, and in the reach it is also estimated that 660 lb./day of BOD is satisfied by using up the DO of the river.

One further example will serve to illustrate this procedure, and to indicate how other available information is used as a test. In April-May the average result for Station 14 was 71,100 lb./day of BOD. By natural purification this should have been reduced to 65,330 at Station 15. However, the results at Station 15 showed that it had a BOD load of 79,000 lb./day. Therefore, there was a calculated mid-station added load between Station 14 and Station 15 that amounted to an average of 12,520 lb./day. The calculated mid-station load between Stations 14 and 15 was due to storm spillage, industrial waste loads, and possibly to the lifting of bottom sludge. We know that there are at least 11 combined sanitary-storm sewer outfalls in this portion of the stream and four industrial waste outfalls.

In the April-May period it was found by a separate computation that 7,810 lb./day of storm spillage, and 560 lb./day of industrial waste load spilled into the river between Station 14 and Station 15. These storm spillage and industrial waste loads were computed from limited field and sampling data. They account for over two-thirds of the computed mid-point load.

One other type of mid-station change has been consistently observed in the computations, and has not been unexpected. It involves the settling out of part of the initially flowing BOD to form sludge deposits. Examples of this will be shown below. In brief, the foregoing computation procedure at times indicated a negative change in the loads between sampling points, that is, the amount of flowing BOD remaining at the lower end of the reach was much too small to be accounted for on the basis of natural self-purification of the flowing loads and a k_1 in the neighborhood of 0.139/day. Such disappearance of BOD is accounted for as BOD that has settled to the river bed to form a sludge, as the most likely explanation. As in case of the mid-station loads, some of the resulting computed deposits are negligibly small, and may have resulted from small errors in k_1 or in sample averages. But others are definite and can only be significant deposits.

Suspended and settleable wastes enter the Upper Illinois River System as part of all the wastes that contribute to the pollutional loads. The amount deposited will vary depending upon the waste, the hydraulics of the river system, the rate, and the nature of the decomposition of the waste. In the Upper Illinois River System the average velocities are low - in the 0.1 to 1.0 foot per second range. At the lower velocities in this range settleable wastes are deposited quickly. This deposited sludge results in a sizeable oxygen demand on the oxygen resources of the stream.

Estimating the locations and magnitudes of significant sludge deposits and their resulting oxygen demands has been one of the most difficult parts of these analyses. In the first place, the location of such deposits is strongly affected by river velocities, and the latter change with flow changes, storm flows, river traffic, and like effects. Thus, the location of a significantly large deposit may, on the average, shift somewhat from one month to the next. Its magnitude may also vary in like fashion, depending, for instance, upon the frequency, location, and magnitude of storms.

Added to these effects, the river barge traffic churns up, and resuspends the once-settled bottom sludges, and it does so on an erratic, or nonregular, basis. Barge and boat passages average 10 to 20 per day. In this fashion, the solids that may earlier have been deposited in two or three definite locations become resuspended and redistributed. These computations indicate that as a result of such influencing factors virtually the entire river bed has at least some small organic sludge deposit and demand. The location and magnitudes of such deposits and demands are not stable over long periods of time, but rather are expected to shift on a nonpredictable basis. As a result, one can only estimate average effects for specific survey periods, and it is not to be expected that these locations and magnitudes will necessarily agree from one survey period to the next.

With these points in mind an example of the computation of sludge deposits is useful. Referring again to the April-May 1961 survey period, let us examine the reach between Stations 6 and 7. Referring to Table IX-4 and Figure IX-1, the combined flowing BOD from Station 5 and the North Branch, Station 6, was 62,190 lb./day. At the lower end of the reach, Station 7, a flowing load of only 53,160 lb./day remained, as indicated by the field survey. The time of travel was only 0.108 days, hence this sharp reduction in flowing load could not have resulted from natural self-purification at $k_1 = 0.139$/day. The reduction is too great to be accounted for on the basis of errors in k_1 or in sample averages. As a result, it is estimated by the foregoing procedures that 1,410 lb./day of BOD were satisfied in the usual fashion in the flowing stream, and 7,770 lb./day disappeared from the flowing stream to settle on the river bed.

There are known BOD loads coming into the main channel Upper Illinois River System at six points. These are at Station 1 at Wilmette, the Northside Sewage Treatment Plant, the North Branch Chicago River, the Chicago River, the Southwest Sewage Treatment Plant, and the Cal-Sag Channel. These known sources of loads are tabulated in Table IX-1. The totals of these six loads for each of the five study periods were as follows: 195,570; 255,300; 171,940; 160,330, and 206,760 pounds of ultimate first-stage BOD per day. The averages for each of these loads were 16,190; 24,000; 3,210; 10,870; 122,240, and 21,870 pounds per day.

From the observed BOD and DO values at sampling stations, computations have revealed numerous mid-station loads. These are tabulated for the four study periods in Table IX-2. In each of the study periods the load inflow (plus) changes are greater than the load drop-out (minus) changes. The average for added mid-station loads was 157,250. The average for deposited BOD was 82,900. These loads come into the system from storm spillage, plant discharges and industrial wastes.

In a separate study of industrial wastes, it was found that 54,300 pounds were discharged into the main channel Upper Illinois River. From the Storm Spillage investigations, the spillage from combined storm and sewage was computed to be 56,000 pounds. The sum of these two figures totals 110,300pounds. This accounts for 70 per cent of the estimated 157,250 lb./day of mid-station loads. These figures are summarized in Table IX-1. Details of the computations are in Table IX-15.

Table IX-2 summarizes the estimated mid-station pollution load changes. As may be seen, for the April-May 1961 survey period specifically, the estimated total of BOD that deposited in the Upper Illinois River System was 77,090 lb./day. As will be seen in the next section, during the same period the total amount of oxygen estimated to have been demanded by the existing sludge deposits was 57,030 lb./day. In view of the many difficulties involved in the analysis of sludge effects, the agreement between these quantities is considered quite satisfactory.

The accompanying tables and figures present all of the computations involved in the estimating of the pollution load picture for the Upper River System.

DO Balances

Having established a best estimate of the extent of pollution of the Upper River System, and the resulting oxygen demands of the flowing loads, it remains to conduct the balance of these demands against the available oxygen resources.

Referring to the earlier discussion of procedures, the available assets include the tributary DO available at the beginning of any reach, DO added between sampling stations by tributary flows, and the oxygen income from reaeration. The liabilities for each reach have been estimated by the BOD balances. The procedure now, for each river reach, is to total the available assets, deduct the estimated oxygen demands, and test the result against the observed DO at the downstream end of the reach. These computations are given in Tables IX-5, 7, 9, 11, & 13 for the April-May, June, July, and August, and Jan. survey periods, and the results for the April-May, July, and August periods are shown in Figures IX-2, 4, and 6.

As in the case of the BOD balances and integration of pollution loads, the DO balances have revealed some mid-station changes, some positive and more negative. In essence, occasional positive changes occurred, indicating an apparent additional oxygen resource added between the stations. In most cases this apparent added oxygen is small in magnitude and may be unreal, having resulted from minor deviations of the DO sample averages from the true mean, or from minor differences between the real and assumed values for k_2 as derived from the O'Connor-Dobbins model. On the other hand, depending upon the hour of sampling and other factors, at some locations there could have been oxygen added by the photosynthetic activities of algae.

Certain of these positive mid-reach changes are relatively large, notably in the reaches below Station 19, and cannot be neglected on the basis of minor computational error. They may arise due to the photosynthetic activities of algae, as indicated in the introductory section on stream assets. They may also occur, however, as the result of significant error in the apparently observed average DO at sampling stations where the DO is frequently at or near zero. When DO becomes fully exhausted, it might well have become negative if this were physically possible. This is the situation in which some of the existing load may disappear from the stream as noxious gases because no further physical alternative exists. Thus, averaging these observed zero values for DO with other real, or positive, values can lead to larger error, and would result an apparent additional source of DO. It is also well to note that when DO's in the stream are zero it is extremely difficult to demonstrate this value by usual sampling and laboratory methods. The driving force for reaeration is relatively tremendous, and henve "observed" DO's of 0.2, 0.3, 0.5 mg/l. may well be actually zero.

The larger apparent positive mid-station changes in DO, therefore, may be due to photosynthesis or they may be due to the difficulties that occur with zero DO's. The latter is thought to be a distinct possibility in the reaches below Station 19, and, for instance, in the August 1961 period immediately below Station 9. In view of the general agreement obtained between computed and observed results on the basis of the assumptions used, these particular difficulties do not detract significantly from the estimates of the self-purification capacity of the Upper River System.

It is well to note also in this regard that Station 12 was a necessary but particularly poor sampling point in terms of the difficulties encountered in obtaining representative samples. These difficulties arose because of the proximity of Station 12 to the confluence of the mainstem and North Branch of the Chicago River, and it is quite likely that at times the sample at Station 12 did not represent a proper mixture of these two streams. This also may account for the large apparent positive mid-station change calculated below Station 9 in the August 1961 survey period.

In most cases, as shown by the tables, the estimated mid-station changes were negative, indicating an unexpectedly large loss of stream oxygen between two sampling points. Again also, a number of the estimated magnitudes are negligibly small and may have arisen through minor differences between the actual situation of the moment and the basic computational assumptions. In a number of cases, however, the apparent mid-station loss of oxygen is unquestionably real, and is the result of the oxygen demands of underlying organic sludge deposits. As indicated in the tables, this effect is prevalent throughout most of the Upper River System.

The resulting estimates of bottom sludge oxygen demands (BSOD) are presented in Table IX-3. It is of interest to compare these summaries with those of Table IX-2, where the estimated mid-station sludge deposits are summarized. Averaging the negative (drop-out) totals from Table IX-2 yields a grand estimate of 82,900 lb./day of sludge depositing throughout the Upper River System. Averaging the totals of Table IX-3 (BSOD), on the other hand, yields a grand average for the System of 58,600 lb./day of oxygen being demanded by sludge deposits.

Thus, the estimates indicate that the oxygen demands of river sludge deposits in the Upper River System amount to 71 per cent of the amount of BOD deposited daily. It may be recalled in this regard that the maximum, or equilibrium, demand would be 100 per cent of the daily deposit, and many stream effects tend to prevent this full equilibrium from being reached. The erratic and nonpredictable pattern of loading with settleable BOD, the random occurrence of storms, and the known resuspension and redistribution of existing sludge beds, all tend to create an exceptionally complex problem in analysis. In view of these facts, and considering that the estimates of daily deposit and daily demand have been made along separate computational paths, the figure of 71 per cent of equilibrium is entirely in keeping with what should be expected, and the general estimates of daily deposit and daily sludge demand are considered quite reliable.

The importance of these sludge demands in the Upper River System is readily demonstrated by comparing the 58,600 lb./day of demand to the total estimated oxygen income from reaeration. Reference to Tables IX-5, 7, 9,11 & 13, yields the necessary data. Totalling the reaeration income for each survey period, and averaging the five totals, an average of 52,600 lb./day of total reaeration income is obtained for the Upper River System. Thus, the oxygen demand from organic sludge deposits is equal for practical purposes to the total oxygen income from reaeration.

Another way in which the order of magnitude of these sludge demands may be indicated is to consider the amount of oxygen that can be held by saturated water. At 25°C, one thousand cfs of water saturated with dissolved oxygen contains 45,000 lb./day of oxygen. This figure may be compared to the estimated 58,600 lb./day of existing sludge demands.

Summary

BOD and DO profiles have been constructed from observed conditions in the Upper Illinois River System. The three BOD profiles show the same general picture, namely, a load coming into the stream at Station 1, a sizeable load added by the Northside Treatment Plant, and mid-station loads that maintain the high BOD level down to the Chicago River.

The Chicago River brings in a load, and the BOD is raised by mid-station loads down to the Southside plant. There are more combined sewer outfalls between the Chicago River and the Southside plant than in any other 10-mile stretch of the river. These outfalls drain a very large portion of the city. The general level of the BOD profile is upward in the reaches from Chicago River to the Southside plant due mainly to these mid-station loads.

At the Southside plant the largest single load is added to the stream. From this location the stream slowly oxidizes its pollutional load. At Station 22, Lockport Dam, the remaining BOD load is over 140,000 pounds of ultimate first-stage BOD per day. This load has rapidly exhausted the DO assets of the stream.

Sludge deposits and resulting oxygen demands occur to greater or lesser degree throughout the entire Upper River System. The demands for oxygen from these deposits equal the entire oxygen income from reaeration, in the neighborhood of 60,000 lb./day. They are greater by about 15,000 lb./day than the entire DO that can be carried by 1,000 cfs of water saturated with oxygen at 25°C.

The DO assets of the stream, starting at near saturation at Station 1, are rapidly depleted as the stream approaches Station 9. In April-May, DO dropped from 12.0 mg/l. at Station 1 to 5.2 mg/l. at Station 9. In June this low point was 3.0 mg/l.; in July it was 1.0 mg/l.; and in August it was only 0.26 mg/l., or, effectively, zero.

These low DO values are the result of heavy loads being added to the river, the higher temperatures resulting in higher consumption rates of DO, and the lower summer flows, all combined with the large sludge oxygen demands. In August the river was rapidly approaching anaerobic conditions at Station 9, just upstream from the Chicago River.

In each of the study periods, the Chicago River brought new DO assets into the stream, increasing the DO level. However, the heavy loads in the river immediately started to lower the DO. With the existing heavy BOD load, sludge demands, and added loads from the Chicago River to the Southside plant, the DO fell from 3.0 mg/l. to less than 1.0 mg/l. in August.

Along with its heavy BOD load, the WSW contributed substantial quantities of oxygen but the DO profiles again fell rapidly to very low levels in the reaches above the Lockport Dam. The Calumet-Sag Channel brought in a small amount of added DO. The DO of the stream is usually below 1.0 mg/l. in these reaches, and often completely exhausted.

Thus, the self-purification model outlined earlier, has provided a rational and adequate explanation of dissolved oxygen levels as observed in the Upper Illinois River System.

The Lower Illinois River System

The Lower Illinois River System was sampled for monthly periods during November-December 1961, March-April 1962, and July-August

1962. The known estimated loads from community wastes are 225,000 pounds ultimate first-stage BOD per day. The known estimated loads from industrial wastes are 80,000 pounds per day. These loads are imposed on the Lower River System and its tributaries over a length of more than 200 miles. The order of magnitude of the loads is similar to that in the Upper River. However, the greater length of the river, the greater dilution, the longer times of travel, and the more advanced stages of self-purification, all result in the Lower River generally being of better quality than the Upper River. This is the picture for November 1961 and the March 1961 study periods. The July 1962 study period tells a more complex, and a somewhat more critical story.

The DO during November 1961 and March 1962 was near saturation for the entire length. For this reason, BOD-DO balances were not computed for the Lower River for any of the three study periods.

The Lower River shows clear evidence of nitrification oxidation in the July 1962 study period. In July 1962, the flows were relatively low, temperatures high, and BOD at moderate levels. DO values fell to the lowest levels of the three study periods. From about 8.0 mg./l. at the upstream stations, DO fell to 4.0 mg./l. in the lower reaches. During this period the BOD levels fell from a high of 12.0 mg./l. to 6.0 mg./l. At the same time nitrates rose from 2.0 mg./l. to nearly 4.0 mg./l., indicating extensive nitrification. Nitrification of ammonia to nitrites and then to nitrates represents the final stage of the nitrogen cycle, and results in an oxygen demand. These changes represent satisfied demands on the self-purification capacity of the stream.

The summary data for the Lower Illinois River System are given in Tables 17 through 21 for Flows, BOD, DO, Temperature, and Nitrates, respectively.

X SUMMARY OF EXISTING CONDITIONS

This chapter presents a summary of the principal conclusions revealed by this study of the Illinois River system. It reviews in general terms the water resources, uses, and water borne wastes as found by inventory methods. It presents general conclusions, resulting from laboratory and field observations, of the physical, chemical, radiochemical, and biological parameters studied, and includes a quantitative evaluation of waste loads and assimilative capacity.

The principal conclusions derived from a study of the data presented in this report are listed below:

1. Surface water is the principal source of water supply in the Illinois River Basin on the basis of volume of water pumped and population served. Lake Michigan is the principal source of the surface water used. The Chicago water supply system plus the direct diversion from Lake Michigan at Chicago is also the principal direct or indirect source of water for other major uses in the upper basin, namely, industrial water, power generation, navigation on the Illinois Waterway, and waste assimilation and transport.

2. About 2,400,000 population equivalents of oxygen-demanding wastes are discharged to streams in the Illinois River Basin. Of this amount, about 1,400,000 are from municipal sources and 1,000,000 are from independent industrial discharges. In the Upper Illinois River Basin above the Kankakee River, the total population equivalents discharged to the streams are about 1,500,000, of which about 1,000,000 are from municipal sources. Nearly all municipal wastes in the Upper Illinois River Basin receive secondary treatment. In the Lower Illinois River Basin, the population equivalents discharged to the streams are about 900,000, of which about 400,000 are from municipal sources.

3. The physical appearance of the Upper Illinois River reflects the many sources of pollution received. It is littered with rubbish and garbage, including debris large enough to be of hazard to small craft. Oil slicks and foam are prevalent throughout its length. This condition also prevails for many miles of the lower river, where it is gradually transformed by the appearance of green vegetation. Much of this general pollution can be prevented by adequate policing.

4. Of the many physical and chemical parameters studied, it was found that the water quality of the Illinois River system was affected principally by abnormal temperature conditions, low dissolved oxygen, high BOD, suspended solids, the ABS content, significant loads of nitrogen and phosphate wastes, toxic metals, and persistent organic compounds.

A. The thermal loads imposed on the Upper Illinois River system resulted in a gradual rise in temperature of about 9° C. throughout the system, thus decreasing the oxygen containing capacity of the stream and increasing the rate at which oxygen is consumed by decomposition of organic wastes.

B. The pollution loads imposed on the Upper Illinois River system exceed its natural capacity for waste stabilization and recovery. The loads seriously deplete oxygen reserves needed to maintain minimal DO levels. No reserve is available against the effects of these loads. Numerous individual observations of zero DO confirmed the observations of nuisance conditions.

C. There are significant quantities of settleable organic and inorganic solids present in the upper waterway. These result in sludge deposits of considerable volume, which exert a heavy and continuous demand on the oxygen resources of the waterway and are a major factor in reducing oxygen concentrations to the low levels found.

D. In addition to oxygen-consuming carbonaceous wastes, the river system carried substantial loads of organic and ammonia nitrogen. The oxygen-consuming (nitrogenous BOD) load due to the nitrogenous matter resulted in significant oxygen depletion in downstream portions of the Illinois River system.

E. The phosphate load carried by the Illinois River can be a significant nutrient factor contributing to the prolific population increases of plankton and algae which subsequently result in nuisance conditions to downstream water users.

F. The presence of toxic metals has been detected at various locations in the Upper and Lower River system. However, levels found were within the limits set forth in the U.S. Public Health Service Drinking Water Standards.

G. Significant quantities of persistent organic materials, as exemplified by the ABS and carbon absorption analyses, are being discharged to the river system. These chemicals resist biological degradation and can be the cause of damage to downstream water uses. Their significance to water quality has been recognized by inclusion in the U.S. Public Health Service Drinking Water Standards. (ABS at 0.5 mg/l, and Carbon Chloroform Extract at 0.2 mg/l).

5. Under existing fallout conditions and controls by both the Atomic Energy Commission and State Agencies, radiation levels in the river system were within prescribed Radiation Protection Guides.

6. Biological degradation was evidenced throughout the main stem of the Upper Illinois River system, including the Cal Sag tributary system. Degradation was severe as far downstream as mile point IR 271.5; there was a gradual improvement in quality from that point downstream to IR 194.1 where a definite tendency toward recovery was noted. Extreme biological depression occurred in certain reaches of the Upper Illinois River system during the summer months when populations of organisms very tolerant to pollution, such as sludgeworms, were greatly reduced although bottom sludge banks existed. The flora and fauna of the Lower Illinois River indicated further progress toward recovery below mile point 194.1, in that organisms intolerant of low dissolved oxygen conditions or high concentrations of toxic and inhibitory materials were common in that reach of the stream. An evaluation of the fish populations in the Upper Illinois River substantiated the other biological data.

7. Significantly high coliform levels were found throughout the waterway system. Starting with the low levels found in Lake Michigan water at the several inlets, the levels in the Upper Illinois River system increased at numerous points due to additional waste discharges reaching the system. These high concentrations represented gross pollution and were of public health significance because of their association with waste discharges known to contain human fecal material. This danger has been confirmed by the finding of varieties of pathogenic bacterial and enteroviruses.

8. The Lower Illinois River reveals evidence of heavy bacterial pollution throughout its length. The natural tendencies of stream purification and bacterial die-off are offset by fresh additions of pollution originating from tributary streams and cities located in the drainage basin.

9. A quantitative evaluation of the total organic waste loads discharged to the Upper River system indicated the presence of substantial sources of oxygen demand - equivalent to about 150,000 pounds of ultimate BOD daily. This was in addition to the loads contributed from treatment plant effluents, and other known sources. These demands may be due to resuspension of sludge deposits, storm water spillage, unconnected outfalls or a combination of these factors. Over 70 percent of this additional load can be accounted for through information gained in studies of storm water overflow and industrial waste discharges direct to the Upper Illinois River system. The oxygen demand of sludge deposits in the Upper Illinois River system was found to be about 60,000 lb./day. These demands, totalling about 400,000 lbs., exceeded the natural self-purification capacity of the Upper Illinois River system.